

# WRITING CHEMICAL EQUATIONS

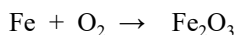
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## I. THE MEANING OF A CHEMICAL EQUATION

A chemical equation is a chemist's shorthand expression for describing a chemical change. As an example, consider what takes place when iron rusts. The equation for this change is:



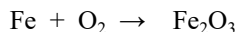
In this expression, the symbols and formulas of the reacting substances, called the **reactants**, are written on the left side of the arrow and the **products** of the reaction are written on the right side. The arrow is read as "gives", "yields", or "forms" and the plus (+) sign is read as "and". When the plus (+) sign appears between the formulas for two reactants, it can be read as "reacts with". (The + sign does not imply mathematical addition.)

The equation, above, can be read as *iron reacts with oxygen to yield (or form) iron(III) oxide*.

## II. BALANCING A CHEMICAL EQUATION

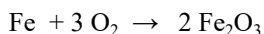
As it is written, the equation indicates in a qualitative way what substances are consumed in the reaction and what new substances are formed. In order to have quantitative information about the reaction, the equation must be balanced so that it conforms to the *Law of Conservation of Matter*. That is, there must be the same number of atoms of each element on the right hand side of the equation as there are on the left hand side.

If the number of atoms of each element in the equation above are counted, it is observed that there are 1 atom of Fe and 2 atoms of O on the left side and 2 atoms Fe and 3 atoms of O on the right.

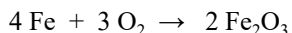


<i>Left side:</i>	<i>Right side:</i>
1 atom Fe	2 atoms Fe
2 atoms O	3 atoms O

The balancing of the equation is accomplished by introducing the proper number or coefficient before each formula. To balance the number of O atoms, write a 3 in front of the O<sub>2</sub> and a 2 in front of the Fe<sub>2</sub>O<sub>3</sub>:



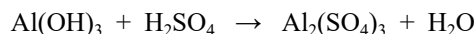
The equation, above, now has 6 atoms of O on each side, but the Fe atoms are not balanced. Since there is 1 atom of Fe on the left and 4 atoms of Fe on the right, the Fe atoms can be balanced by writing a 4 in front of the Fe:



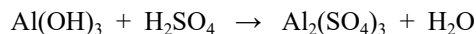
This equation is now balanced. It contains 4 atoms of Fe and 6 atoms of O on each side of the equation. The equation is interpreted to mean that 4 atoms of Fe will reaction with 3 molecules of O<sub>2</sub> to form 2 molecules of Fe<sub>2</sub>O<sub>3</sub>.

It is important to note that the ***balancing of an equation is accomplished by placing numbers in front of the proper atoms or molecules*** and **not** as subscripts. In an equation, all chemical species appear as correct formula units. The addition (or change) of a subscript changes the meaning of the formula unit and of the equation. ***Coefficients in front of a formula unit multiply that entire formula unit.***

Another example of balancing an equation is:



Counting the atoms of each element in the equation it is found that there are 1 atom Al, 7 atoms O, 5 atoms H, and 1 atom S on the left side and 2 atoms Al, 13 atoms O, 2 atoms H, and 3 atoms S on the right side.



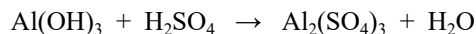
*Left side:*

1 atom Al  
7 atoms O  
5 atoms H  
1 atom S

*Right side:*

2 atoms Al  
13 atoms O  
2 atoms H  
3 atoms S

The counting, however, can be simplified by observing that the S and O in the  $\text{SO}_4$  polyatomic ion acts as a single unbreakable unit in this equation. Recounting, using the  $\text{SO}_4$  as a single unit, it is found that there are 1 atom Al, 3 atoms O, 5 atoms H, and 1  $\text{SO}_4$  polyatomic ion on the left side and 2 atoms Al, 1 O atom, 2 H atoms, and 3  $\text{SO}_4$  polyatomic ions on the right side.



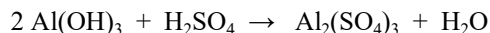
*Left side:*

1 atom Al  
3 atoms O  
5 atoms H  
1  $\text{SO}_4$  group

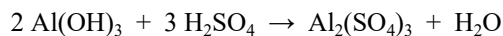
*Right side:*

2 atoms Al  
1 atoms O  
2 atoms H  
3  $\text{SO}_4$  groups

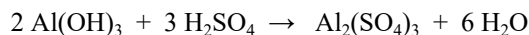
Starting with Al, the atoms of Al can be balanced by writing a 2 in front of the  $\text{Al(OH)}_3$ :



Looking at the  $\text{SO}_4$  ions, these are balanced by writing a 3 in front of the  $\text{H}_2\text{SO}_4$ :



Now, only the O atoms and H atoms remain unbalanced. There are 6 atoms of O and 12 atoms of H on the left hand side of the equation and only 1 atom O and 2 atoms H on the right side. These can be balanced by writing a 6 in front of the  $\text{H}_2\text{O}$ :



The equation is now balanced and it is interpreted to mean that 2 molecules of  $\text{Al(OH)}_3$  react with 3 molecules of  $\text{H}_2\text{SO}_4$  to form 1 molecule of  $\text{Al}_2(\text{SO}_4)_3$  and 6 molecules  $\text{H}_2\text{O}$ .

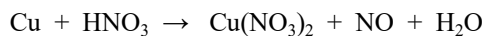
### Problems: Balancing chemical equations

Balance each of the following equations:

1.  $\text{H}_2 + \text{Br}_2 \rightarrow \text{HBr}$
2.  $\text{N}_2 + \text{H}_2 \rightarrow \text{NH}_3$
3.  $\text{Sb} + \text{O}_2 \rightarrow \text{Sb}_4\text{O}_6$
4.  $\text{Cu}(\text{NO}_3)_2 \rightarrow \text{CuO} + \text{NO}_2 + \text{O}_2$
5.  $(\text{NH}_4)_2\text{Cr}_2\text{O}_7 \rightarrow \text{Cr}_2\text{O}_3 + \text{N}_2 + \text{H}_2\text{O}$
6.  $\text{C}_2\text{H}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
7.  $\text{Al} + \text{HgCl}_2 \rightarrow \text{AlCl}_3 + \text{Hg}$
8.  $\text{FeS} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 + \text{SO}_2$
9.  $\text{KOH} + \text{Cl}_2 \rightarrow \text{KCl} + \text{KClO} + \text{H}_2\text{O}$
10.  $\text{Ca}(\text{OH})_2 + \text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{O}$
11.  $\text{BaCl}_2 + \text{Na}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + \text{NaCl}$
12.  $\text{CrBr}_3 + \text{Na}_2\text{SiO}_3 \rightarrow \text{Cr}_2(\text{SiO}_3)_3 + \text{NaBr}$

Not all equations can be easily balanced by the method used here. In some equations the oxidation numbers of some atoms change during the reaction. Such equations are known as **oxidation-reduction** equations and many of these require special methods to balance them. Although the balancing of oxidation-reduction equations will not be covered in this tutorial, the following oxidation reduction equation is provided as an exercise:

Balance the following equation:

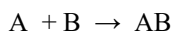


### III. TYPES OF CHEMICAL REACTIONS

Most inorganic reactions can be classified into one of five general categories: direct union or combination, decomposition, displacement, metathesis or double displacement, and combustion reactions. Each of these will be discussed in more detail in the following sections.

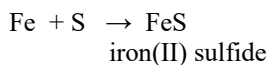
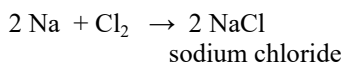
#### 1. Direct Union or Combination Reactions

Any reaction in which two or more substances combine to form a single product is a *direct union* or *combination* reaction. The general form of a direct union reaction is

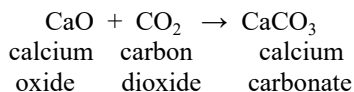
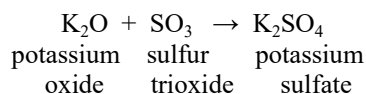


This type of reaction generally takes place between the following types of compounds:

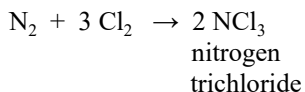
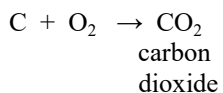
##### a. A metal + non-metal



##### b. Metal oxide + non-metal oxide

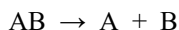


##### c. Non-metal + non-metal

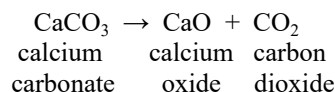
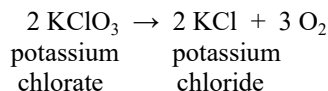
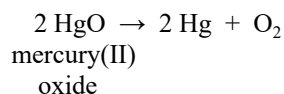


#### 2. Decomposition Reactions

Decomposition is the reverse of combination. That is, a single reactant is broken down into two or more products either elements or compounds. A decomposition reaction will take place because the compound is unstable or as a result of heating or electrical decomposition (electrolysis). The general form for a decomposition reaction is:



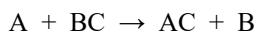
Some examples of decomposition reactions are:



To understand how to predict products of decomposition reactions, see Section V. The Effect of Heat on Metallic Compounds, page 11.

### 3. Displacement Reactions (Sometimes called oxidation-reduction equations)

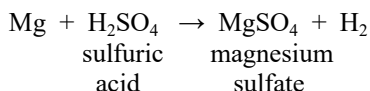
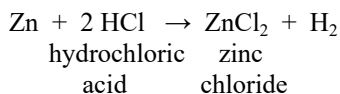
A displacement reaction involves an element reacting with a compound whereby the element displaces a second element from the compound. The general form of this type reaction is:



Displacement reactions usually occur between the following combinations:

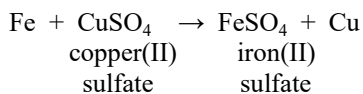
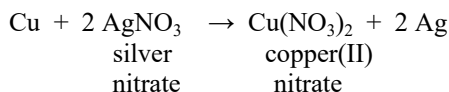
#### a. An active metal + an acid

When a metal which is above hydrogen in the activity series is reacted with an acid, hydrogen is liberated and a salt is formed. (Refer to Section IV, The Electromotive Series, page 9)



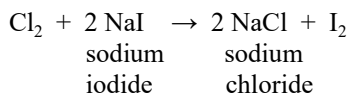
#### b. A metal + a salt

Each metal in the activity series displaces any metals below it to form a salt in solution. (Refer to Section IV, The Electromotive Series, page 9)



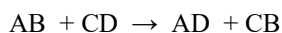
### c. A Halogen + halide salt

A halogen (F, Cl, Br, I, At) will displace any less active halogen from a halide salt. The order of activity decreases going from top to bottom down the halogen family in the periodic table.



## 4. Metathesis or Double Displacement Reactions

A metathesis is a double displacement reaction that usually occurs in water solution. The general form of a metathesis reaction is:



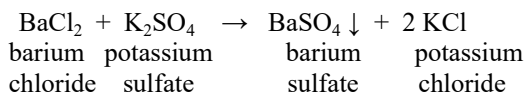
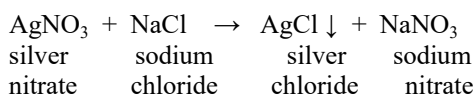
In order to have any appreciable degree of completion of metathesis reactions, one or both of the products must become unavailable for the reverse reaction. the principal conditions that favor the completion of these reactions are:

- (1) Formation of an insoluble compound - a precipitate
- (2) Formation of a gas
- (3) Formation of water

Metathesis reactions are generally classified as precipitation reactions or as neutralization reactions.

### a. Precipitation Reactions

In this type of reaction, two compounds which are water soluble react to form two new compounds, one of which is a precipitate (i.e. insoluble in water). The precipitate is often indicated by an arrow pointing downward, ↓, written next to its formula.



In order to determine which one of the products will be the precipitate requires a knowledge of the solubilities of salts in water. The rules governing the solubility of common salts are given below:

### THE SOLUBILITY RULES

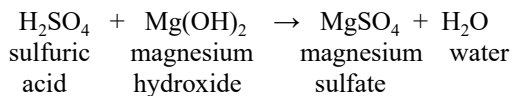
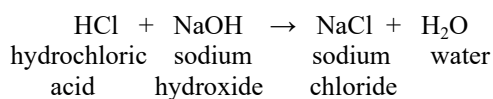
1. All sodium, potassium, and ammonium salts are soluble in water.
2. The nitrates, chlorates, and acetates of all metals are soluble in water. Silver acetate is sparingly soluble.
3. The chlorides, bromides, and iodides of all metals except lead, silver, and mercury(I) are soluble in water.  $\text{PbCl}_2$ ,  $\text{PbBr}_2$ , and  $\text{PbI}_2$  are soluble in hot water.

4. The sulfates of all metals except lead, mercury(I), barium, and calcium are soluble in water.  $\text{Ag}_2\text{SO}_4$  is slightly soluble.
5. The carbonates, phosphates, borates, sulfites, chromates, and arsenates of all metal except sodium, potassium, and ammonium are insoluble in water.
6. The sulfides of all metals except barium, calcium, magnesium, sodium, potassium, and ammonium are insoluble in water.
7. The hydroxides of sodium, potassium, and ammonium are very soluble in water. The hydroxides of calcium and barium are moderately soluble. The oxides and hydroxides of all other metals are insoluble.

**b. Neutralization Reactions** (sometimes called acid-base reactions)

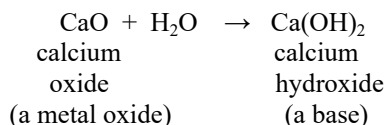
A neutralization reaction occurs between an acidic compound and a basic compound to form a chemical salt and water.

**1. Reaction between an acid and a base**

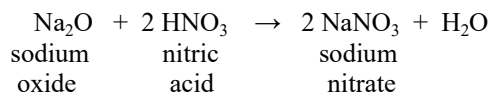
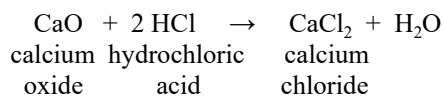


**2. Reaction between a metal oxide and an acid.**

When oxides of many metals are added to water, bases are formed.

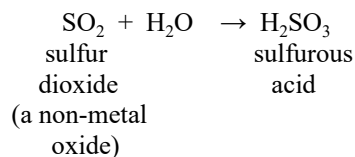


Generally, these metal oxides are called basic anhydrides and they act like bases when mixed with acids.

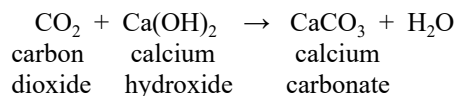
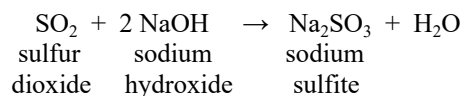


### 3. Reaction between a non-metal oxide and a base.

Many non-metal oxides are classified as acid anhydrides. These form acids when mixed with water.

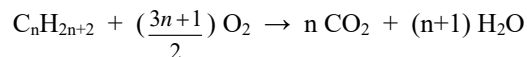


Non-metal oxides act as acids when mixed with a base.



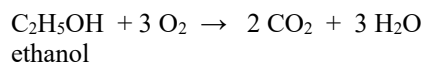
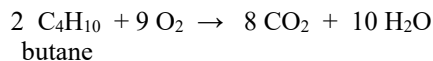
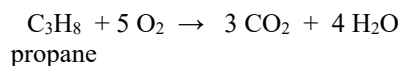
### 5. Combustion Reactions

Combustion reactions generally apply to organic compounds, such as hydrocarbons, which are used as fuels. In these cases, the compound is being burned in air (or oxygen) and producing carbon dioxide and water as products. A general form for a combustion reaction is:



Note: The actual coefficients will vary based on the composition of the starting compound.

Some examples of combustion reactions are:





## IV. THE ELECTROMOTIVE (ACTIVITY) SERIES OF METALS

### The Activity Series of Metals

1. Li - Lithium
2. K - Potassium
3. Ba - Barium
4. Sr - Strontium
5. Ca - Calcium
6. Na - Sodium
7. Mg - Magnesium
8. Al - Aluminum
9. Mn - Manganese
10. Zn - Zinc
11. Cr - Chromium
12. Fe - Iron
13. Cd - Cadmium
14. Co - Cobalt
15. Ni - Nickel
16. Sn - Tin
17. Pb - Lead
18. H - HYDROGEN
19. Sb - Antimony
20. As - Arsenic
21. Bi - Bismuth
22. Cu - Copper
23. Hg - Mercury(I)
24. Ag - Silver
25. Pd - Palladium
26. Hg - Mercury(II)
27. Pt - Platinum
28. Au - Gold

### Facts About the Activity Series

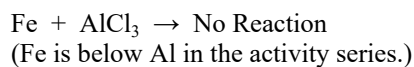
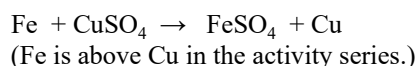
- a. The metals are arranged in the order of decreasing activity (i.e. their ability to pass into ionic form by losing electrons).

Example:

Lithium is more active than potassium, while potassium is more active than barium, etc...

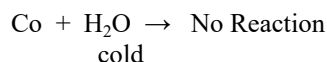
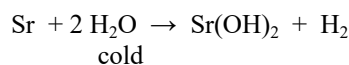
- b. Each metal displaces any metal below it from dilute water solutions.

Example:



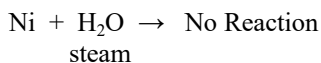
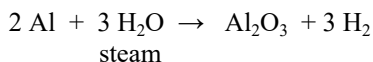
- c. Metals 1 - 6 react with cold water to liberate hydrogen, forming metal hydroxides. Metal 7 (Mg) displaces hydrogen from hot water and reacts very slowly with cold water.

Example:



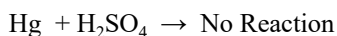
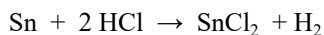
- d. Metals 1-13 react with steam to liberate hydrogen

Example:

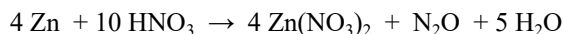


- e. Metals 1-17 react with acids to liberate hydrogen

Example:



Reaction of metals with nitric acid results in a decomposition of the nitric acid along with a displacement reaction. With active metals such as iron and zinc, the reaction with concentrated nitric acid is:

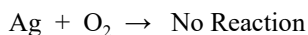
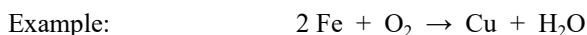


With less active metals, such as copper, the reaction with concentrated nitric acid is:

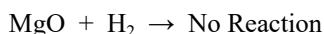


Concentrated nitric acid will react with metals 19-27 similar to the reaction with copper, above.

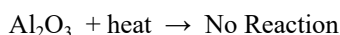
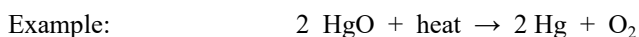
- f. Metals 1-23 react with oxygen to form oxides. The oxides of Ag, Pd, Pt, and Au can be prepared only by indirect methods.



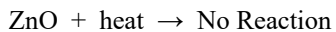
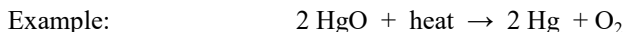
- g. The oxides of metals 12-29 can be reduced by hydrogen to yield the metal and water. The other oxides cannot be reduced by hydrogen.



- h. The oxides of metals 23-29 can be decomposed by the heat of a Bunsen burner. The other oxides cannot be decomposed by the heat of a Bunsen burner.



- i. It is to be noted that the most active elements form the most stable compounds.



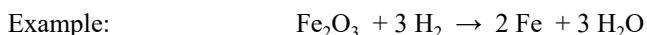
Since Zn is more active than Hg, ZnO is more stable than HgO and it cannot be decomposed by simple heating.

**NOTE:** Examine the list of elements in the Activity Series on the preceding page. Rather than trying to memorize the entire list, the order of the elements in the series can be related to the periodic table. In general, Group IA elements are at the top followed by Group IIA elements and then Group IIIA elements. Next are the common transition elements, then Group IVA elements followed by hydrogen. Below hydrogen are the Group VA elements followed by elements used for dental fillings and jewelry (Group IB and “neighbors”).

## V. THE EFFECT OF HEAT ON METALLIC COMPOUNDS: PREDICTION OF PRODUCTS OF DECOMPOSITION REACTIONS

### 1. On Oxides

The oxides of Fe, Cd, Co, Ni, Sn Pb, Sb, As, Bi, Cu, Hg, Ag, Pd, Pt, and Au (metals 12-29 on the electromotive series) can be reduced by hydrogen to yield the metal and water. The other oxides cannot be reduced by hydrogen.

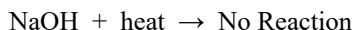
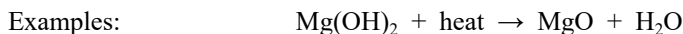


The oxides of Hg, Ag, Pd, Hg, Pt, and Au (metals 23-29 on the electromotive series) can be decomposed by the heat of a Bunsen burner. The other oxides cannot be decomposed by the heat of a Bunsen burner.

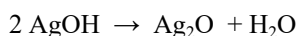
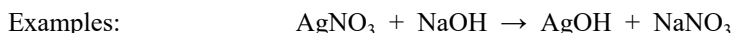


### 2. On Hydroxides

All hydroxides, except those of the alkali metals (Group IA), will lose water when heated forming the metal oxide.

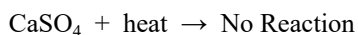


The hydroxides of mercury and silver are not stable, they decompose to form the oxide and water without heating.



### 3. On Sulfates

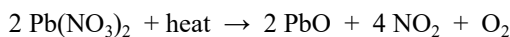
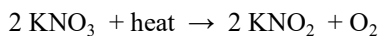
With the exception of the alkali metal (Group IA) and alkaline earth (Group IIA) sulfates, the sulfates of all other metals are decomposed by heat to form the metal oxide and sulfur trioxide.



### 4. On Nitrates

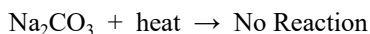
The nitrates of the alkali metals decompose on heating to yield the nitrites and oxygen. All other metal nitrates are decomposed to nitrogen dioxide, oxygen, and the metal oxide on heating.

Examples:

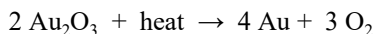


## 5. On Carbonates

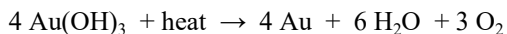
Except for the alkali metal carbonates, all carbonates lose carbon dioxide when heat to form the metal oxide.



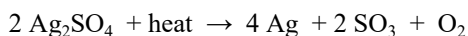
NOTE ON SECTIONS 2-5: The hydroxides, sulfates, nitrates, and carbonates of metals 23-29 in the activity series will yield the metal on heating, since the oxides of these metals are decomposed by heat. For example, the reaction of  $\text{Au}(\text{OH})_3$  will also cause the decomposition of the  $\text{Au}_2\text{O}_3$ :



The overall reaction, combining the above two steps, can be written:

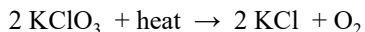


As another example, consider the decomposition of silver sulfate on heating. The overall reaction is:



## 6. On Chlorates

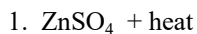
All chlorates decompose on heating to form the chloride of the metal and oxygen gas.



Thermal decomposition of the bromates and iodates result in a number of different products depending on the conditions under which the reactions occur. No general rule can be written for the decomposition of these compounds due to heating.

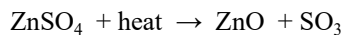
## SAMPLE PROBLEMS

Complete and balance the following equations. If no reaction takes place, indicate by N.R.

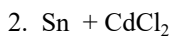


Solution:

This reaction should be recognized as a decomposition reaction (a single compound plus heat). Looking at Section 12.5, concerning the action of heat of sulfates (page 92), it is found that  $\text{ZnSO}_4$  should decompose to form the oxide and  $\text{SO}_3$ . The completed equation should be:

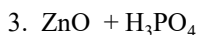
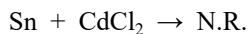


This equation is balanced as written.



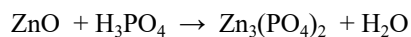
Solution:

A reaction occurring between an element and a compound fits the form of a displacement reaction. Referring to the activity series on page 90, it is observed that Sn is below Cd. Thus Sn is not active enough to replace Cd and no reaction will take place.

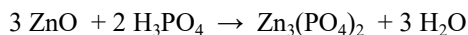


Solution:

This reaction is occurring between a metal oxide (a basic anhydride) and an acid. Therefore, this is a neutralization reaction or a form of the metathesis type reaction. The completed reaction will be:

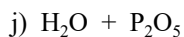
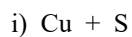
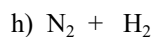
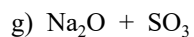
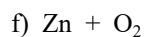
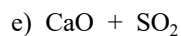
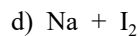
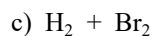
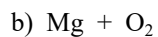
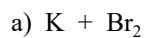


The completed equation must be balanced. (see pages 83-84) The final balanced equation will be:

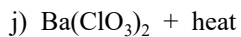
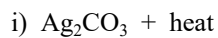
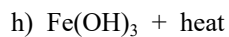
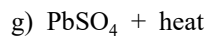
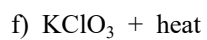
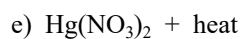
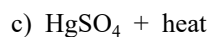
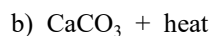
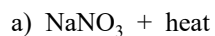


## PROBLEMS: Writing chemical equations.

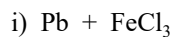
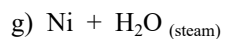
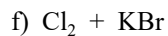
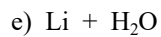
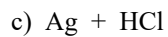
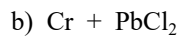
1. Complete and balance the following direct union equations.



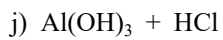
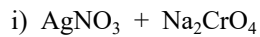
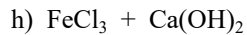
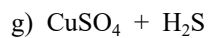
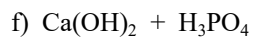
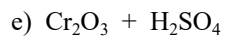
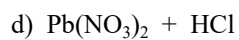
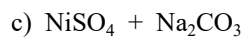
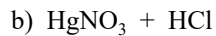
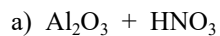
2. Complete and balance the following decomposition equations. If no reaction takes place, indicate by writing N.R.



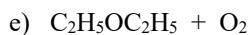
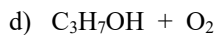
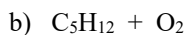
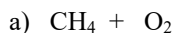
3. Complete and balance the following displacement equations. If no reaction takes place, indicate by writing N.R.



4. Complete and balance the following metathesis equations.



5. Complete and balance the following combustion equations.



6. Classify each of the following equations as direct union, decomposition, displacement, or metathesis reactions AND complete and balance each equation. If no reaction takes place, indicate by N.R.





t) $\text{Al} + \text{Br}_2$	type: _____
u) $\text{Pb}(\text{NO}_3)_2 + \text{Na}_2\text{CrO}_4$	type: _____
v) $\text{Al}(\text{OH})_3 + \text{heat}$	type: _____
w) $\text{Ca}(\text{OH})_2 + \text{H}_3\text{PO}_4$	type: _____
x) $\text{AsCl}_3 + \text{H}_2\text{S}$	type: _____
y) $\text{Cu} + \text{Hg}(\text{NO}_3)_2$	type: _____
z) $\text{Co}_2(\text{SO}_4)_3 + \text{heat}$	type: _____
aa) $\text{Fe} + \text{HNO}_3$	type: _____
bb) $\text{Ni}(\text{NO}_3)_2 + \text{NaOH}$	type: _____
cc) $\text{Na} + \text{H}_2\text{O}$	type: _____
dd) $\text{KCl} + \text{H}_2\text{SO}_4$	type: _____
ee) $\text{Mg} + \text{H}_2\text{O}_{(\text{steam})}$	type: _____
ff) $\text{Ag} + \text{HNO}_3$	type: _____
gg) $\text{CaCO}_3 + \text{HCl}$	type: _____
hh) $\text{KOH} + \text{H}_2\text{SO}_4$	type: _____
ii) $\text{SrI}_2 + \text{Br}_2$	type: _____
jj) $\text{Ba}(\text{NO}_3)_2 + \text{heat}$	type: _____
kk) $\text{Al} + \text{H}_2\text{SO}_4$	type: _____
ll) $\text{PCl}_3 + \text{Cl}_2$	type: _____
mm) $\text{SO}_2 + \text{O}_2$	type: _____
oo) $\text{K}_3\text{PO}_4 + \text{BaCl}_2$	type: _____