Types of Equations

It is most important for a chemist to be able to write correctly balanced equations and to interpret equations written by others. It is also very helpful if he/she knows how to predict the products of certain specific types of reactions.

Purpose: This document is intended to help you, the chemistry student, learn the basics of writing and balancing equations, how to predict the products of four general types of inorganic reactions and how to write and balance equations for the combustion of hydrocarbons. There are also practice exercises for each section.

I. Formulas show chemistry at a standstill. Equations show chemistry in action.

A. Equations show:

1. the reactants which enter into a reaction.
2. the products which are formed by the reaction.
3. the amounts of each substance used and each substance produced.

B. Two important principles to remember:

1. **Every chemical compound has a formula which cannot be altered.**
2. A chemical reaction must account for every atom that is used. This is an application of the Law of Conservation of Matter which states that in a chemical reaction atoms are neither created nor destroyed.

C. Some things to remember about writing equations:

1. The diatomic elements when they stand alone are always written H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2
2. The sign, $\rightarrow$, means "yields" and shows the direction of the action.
3. A small delta, (D), above the arrow shows that heat has been added.
4. A double arrow, $\leftrightarrow$, shows that the reaction is reversible and can go in both directions.
5. Before beginning to balance an equation, check each formula to see that it is correct. **NEVER** change a formula during the balancing of an equation.
6. Balancing is done by placing coefficients in front of the formulas to insure the same number of atoms of each element on both sides of the arrow.

   Practice Balancing Equations

7. Always consult the **Activity Series** of metals and nonmetals before attempting to write equations for replacement reactions.
8. If a reactant or product is a solid, (s) is placed after the formula.

9. If a reactant or product is a gas, (g) is placed after it.
10. If a reactant or product is in water solution, (aq) is placed after it.
11. Some products are unstable and break down (decompose) as they are produced during the reaction. You need to be able to recognize these products when they occur and write the decomposition products in their places.

Examples:

- $H_2CO_{3(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)}$

  Carbonic acid, as in soft drinks, decomposes when it is formed.

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

  Sulfurous acid also decomposes as it is formed.

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

  You can definitely smell the odor of ammonia gas because whenever "ammonium hydroxide" is formed it decomposes into ammonia and water.

D. Rules for writing equations.

1. Write down the formula(s) for any substance entering into the reaction. Place a plus (+) sign between the formulas as needed and put the yield arrow after the last one.
2. Examine the formulas carefully and decide which of the four types of equations applies to the reaction you are considering. On the basis of your decision, write down the correct formulas for all products formed, placing them to the right of the arrow.

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II. Four basic types of chemical reactions:

A. Synthesis (composition):

- two or more elements or compounds may combine to form a more complex compound.
- **Basic form: A + X → AX**

Examples of synthesis reactions:

1. Metal + oxygen → metal oxide

   EX. $2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$

2. Nonmetal + oxygen → nonmetallic oxide

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

3. Metal oxide + water → metallic hydroxide

   EX. $MgO_{(s)} + H_2O_{(l)} \rightarrow Mg(OH)_{2(s)}$

4. Nonmetallic oxide + water → acid

EX. $CO_{2(g)}$ + $H_2O_{(l)}$ → ; $H_2CO_{3(aq)}$

5. Metal + nonmetal → salt

   EX. 2 $Na_{(s)}$ + $Cl_{2(g)}$ → $2NaCl_{(s)}$

6. A few nonmetals combine with each other.

   EX. $2P_{(s)}$ + $3Cl_{2(g)}$ → $2PCl_{3(g)}$

These two reactions must be remembered:

1. $N_{2(g)}$ + $3H_{2(g)}$ → $2NH_{3(g)}$
2. $NH_{3(g)}$ + $H_2O_{(l)}$ → $NH_4OH_{(aq)}$

Practice Predicting Products of Synthesis Reactions

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B. Decomposition:

- A single compound breaks down into its component parts or simpler compounds.
- **Basic form: AX → A + X**

Examples of decomposition reactions:

1. Metallic carbonates, when heated, form metallic oxides and $CO_{2(g)}$.

   EX. $CaCO_{3(s)}$ → $CaO_{(s)}$ + $CO_{2(g)}$

2. Most metallic hydroxides, when heated, decompose into metallic oxides and water.

   EX. $Ca(OH)_{2(s)}$ → $CaO_{(s)}$ + $H_2O_{(g)}$

3. Metallic chlorates, when heated, decompose into metallic chlorides and oxygen.

   EX. $2KClO_{3(s)}$ → $2KCl_{(s)}$ + $3O_{2(g)}$

4. Some acids, when heated, decompose into nonmetallic oxides and water.

   EX. H_2SO_4 → $H_2O_{(l)}$ + $SO_{3(g)}$

5. Some oxides, when heated, decompose.

   EX. $2HgO_{(s)}$ → $2Hg_{(l)}$ + $O_{2(g)}$

6. Some decomposition reactions are produced by electricity.

   EX. $2H_2O_{(l)}$ → $2H_{2(g)}$ + $O_{2(g)}$

   EX. $2NaCl_{(l)}$ → $2Na_{(s)}$ + $Cl_{2(g)}$

Practice Predicting Products of Decomposition Reactions

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C. Replacement:

- a more active element takes the place of another element in a compound and sets the less active one free.
- **Basic form: A + BX → AX + B or AX + Y → AY + X**

Examples of replacement reactions:

1. Replacement of a metal in a compound by a more active metal.

   EX. $Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$

2. Replacement of hydrogen in water by an active metal.

   EX. $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$

   EX. $Mg_{(s)} + H_2O_{(g)} \rightarrow MgO_{(s)} + H_{2(g)}$

3. Replacement of hydrogen in acids by active metals.

   EX. $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

4. Replacement of nonmetals by more active nonmetals.

   EX. $Cl_{2(g)} + 2NaBr_{(aq)} \rightarrow 2NaCl_{(aq)} + Br_{2(l)}$

NOTE: Refer to the **activity series for metals** and nonmetals to predict products of replacement reactions. If the free element is above the element to be replaced in the compound, then the reaction will occurr. If it is below, then no reaction occurs.

Practice Predicting Products of Replacement Reactions

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D. Ionic:

- occurrs between ions in aqueous solution. A reaction will occurr when a pair of ions come together to produce at least one of the following:
  1. a precipitate
  2. a gas
  3. water or some other non-ionized substance.
- Basic form: AX + BY → AY + BX

Examples of ionic reactions:

1. Formation of precipitate.

   EX. $NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}$

   EX. $BaCl_{2(aq)} + Na_2SO_{4(aq)} \rightarrow 2NaCl_{(aq)} + BaSO_{4(s)}$

2. Formation of a gas.

   EX. $HCl_{(aq)} + FeS_{(s)} \rightarrow FeCl_{2(aq)} + H_2S_{(g)}$

3. Formation of water. (If the reaction is between an acid and a base it is called a neutralization reaction.)

EX. $HCl_{(aq)}$ + $NaOH_{(aq)}$ → $NaCl_{(aq)}$ + $H_2O_{(l)}$

4. Formation of a product which decomposes.

EX. $CaCO_{3(s)}$ + $HCl_{(aq)}$ → $CaCl_{2(aq)}$ + $CO_{2(g)}$ + $H_2O_{(l)}$

NOTE: Use the **solubility rules** to decide whether a product of an ionic reaction is insoluble in water and will thus form a precipitate. If a compound is soluble in water then it should be shown as being in aqueous solution, or left as separate ions. It is, in fact, often more desirable to show only those ions that are actually taking part in the actual reaction. Equations of this type are called **net ionic equations**.

Practice Predicting Products of Ionic Reactions

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Combustion of Hydrocarbons:

Another important type of reaction, in addition to the four types above, is that of the combustion of a hydrocarbon. When a hydrocarbon is burned with sufficient oxygen supply, the products are always carbon dioxide and water vapor. If the supply of oxygen is low or restricted, then carbon monoxide will be produced. This is why it is so dangerous to have an automobile engine running inside a closed garage or to use a charcoal grill indoors.

- Hydrocarbon (C_xH_y) + $O_{2(g)}$ → $CO_{2(g)}$ + $H_2O_{(g)}$
- EX. $CH_{4(g)}$ + $2O_{2(g)}$ → $CO_{2(g)}$ + $2H_2O_{(g)}$
- EX. $2C_4H_{10(g)}$ + $13O_{2(g)}$ → $8CO_{2(g)}$ + $10H_2O_{(g)}$

NOTE:

- **Complete combustion** means the higher oxidation number is attained.
- **Incomplete combustion** means the lower oxidation number is attained.
- **The phrase "To burn"** means to add oxygen unless told otherwise.

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