Chapter 10 Chemical Reactions

10.1 Law of Conservation of Matter

The Law of Conservation of Matter tells us that matter (or mass) cannot be created nor destroyed. This is very important in chemical reactions because it means that the mass of the reactants must equal the mass of the products. Or in other words, the number of reactant atoms must equal the number of products atoms. Because of this law chemical reactions must be balanced.

What is a chemical reaction? It is when we us formulas and symbols to describe a chemical reaction, or reactants becoming products:

$$\mathbf{A + B \rightarrow C + D}$$

reactants   **products**

/   \

what we start with   new substance(s) formed

Symbols: You must know which elements are solid, liquid, and gas!!!

(s) = solid   (g) = gas   (l) = liquid   NR = no reaction Δ = heat

(aq) = aqueous solution (ions or compounds dissolved in water)

Example: $H_2SO_4\,(aq) + 2\,NaHCO_3\,(s) \rightarrow Na_2SO_4\,(aq) + 2\,H_2O\,(l) + 2\,CO_2\,(g)$

Diatomic Molecules: You should know the seven elements that exist as **diatomic molecules:**

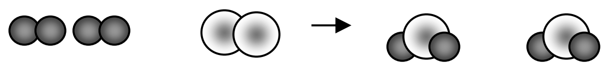
$H_2(g)$	$N_2\,(g)$	$F_2(g)$	$O_2(g)$	$I_2(s)$	$Cl_2(g)$	$Br_2(l)$
“Have	no	fear	of	ice	cold	beer”

However these elements are not diatomic when they are in compounds, for example the correct formula for sodium chloride is NaCl not $NaCl_2$. These elements are only diatomic when they are alone as an element. $CaCl_2$ has two Cl’s because Ca is +2 charged so we need two –1 chlorines. Not because Cl is diatomic.

10.2 Balancing Chemical Reactions

Due to the Law of Conservation, the number of atoms (and the mass) of each element must be equal on both sides of the equation. In other words, you must have the same number of each type of atom on both sides of the arrow. If there are four hydrogen atoms on the left side you must have four hydrogen atoms on the right side as well.

$2\ H_2(g) \quad + \quad O_2(g) \rightarrow \quad 2\ H_2O(g)$



This is a balanced equation – same number of H and O atoms on both sides of the arrow.

☆ To balance an equation, we adjust the <u>coefficients</u> – these are the numbers in front of the reactant and product elements or compounds – **never change the subscripts.** A coefficient multiplies the entire formula that follows it. 2 H_2O means 2 complete water molecules so 4 H atoms and 2 O atoms total are present.

BALANCING SUGGESTIONS:

1) Make sure the **formulas are correct** if you wrote the reaction. If you put a metal and nonmetal together you must CHECK that the CHARGES add to zero charge!
2) Count the # of atoms for each element on both sides of the equation
3) Change coefficients **NOT** subscripts.
4) Balance polyatomic ions as a whole unit if present on both sides of the equation.
5) Save for last elements present in more than 2 formulas
6) Make sure you have smallest set of whole number coefficients possible

Writing balanced reactions from words

Example: Write and balance the reaction between potassium and bromine, which forms solid potassium bromide.

Answer: potassium is a solid that is not diatomic, bromine is a liquid that is diatomic, potassium bromide's correct formula is KBr because K is +1 and Br is -1 in a compound, so it is NOT KBr_2. You never carry a formula over from the reactant side. That is copy catting, which is wrong. So now write the reaction with the correct formula based on charges:

$K(s) \quad + \quad Br_2(l) \quad \rightarrow \quad KBr(s)$

Now we must balance the reaction. We cannot change subscripts now, only coefficients, meaning you cannot make KBr into KBr_2 because that is the wrong formula as explained above.

$2\ K(s) \quad + \quad Br_2(l) \quad \rightarrow \quad 2\ KBr(s)$ (2 K's on each side and 2 Br's on each side)

Summary: You FIRST write a reaction with PROPER FORMULAS, once that is done you cannot change the subscripts. Then you can balance by adding coefficients.

10.3 Types of Chemical Reactions

There are six types of reactions you must learn for this course. The following table gives the name of the reaction, a generic example, and any important notes about it.

Name of Rxn	Generic Example (M is a metal)	Note
Combination	$A + B \rightarrow AB$	combining into one product
Decomposition	$ABC \rightarrow A + B + C$	one reactant breaking down
Combustion	$C_xH_y + O_2(g) \rightarrow CO_2(g) + H_2O(g)$	We will only do hydrocarbon combustion reactions.
Acid Base	$HX + MOH \rightarrow H_2O(l) + MX$	You must correctly write the formula of MX based on charges of the ions.
Single Replacement	$M + AX \rightarrow MX + A$	You must correctly write the formula of MX based on charges of the ions.
Double Replacement	$M_1X + M_2Y \rightarrow M_1Y + M_2X$	You must correctly write the formulas of M_1Y and M_2X based on charges of the ions.

In this class we will provide the products for combination and decomposition reactions with either words or the formulas. **However YOU must write the product formulas for combustion, acid base, single and double replacement reactions yourself!** That is what makes this chapter so hard and probably this is the hardest chapter of the course.

10.4 Combination Reactions $A + B \rightarrow AB$

Combination: Two or more reactants combine to form one product.

Example: $3\ H_2(g) + N_2(g) \rightarrow 2\ NH_3(g)$

Objectives:

- ◊ Be able to identify combination reactions
- ◊ Be able to write combination reactions from words
- ◊ Be able to balance combination reactions

Note: A triangle above the reaction arrow ($\xrightarrow{\Delta}$) indicates that the reactants are heated to make the reaction occur.

10.5 Decomposition Reactions $ABC \rightarrow A + B + C$

Decomposition: One reactant breaks down into two or more products.

Example: $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$

Objectives:

- ◊ Be able to identify decomposition reactions

- ◊ Be able to write decomposition reactions from words
- ◊ Be able to balance decomposition reactions

10.6 Combustion Reactions $C_xH_y + O_2(g) \rightarrow CO_2(g) + H_2O\ (g)$

Combustion: Hydrocarbons (compounds with only C and H atoms) burn in the presence of O_2 gas to produce steam (water vapor) and carbon dioxide gas.

Example: $C_2H_4(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O\ (g)$

Objectives:

- ◊ Be able to identify combustion reactions
- ◊ Given a chemical equation with any hydrocarbon and oxygen gas as reactants, **predict the products** for the reaction ($\Rightarrow H_2O\ (g) + CO_2\ (g)$)
- ◊ Balance combustion reactions (Tip: balance oxygen last)

10.7 Acid Base Neutralization Reactions $HX + MOH \rightarrow H_2O(l) + MX$

Water is formed in some acid base reactions. When the base is a metal hydroxide such as sodium hydroxide, NaOH, an ionic compound is also formed which is called a salt. YOU must write the proper formula based on charges for the salt.

Example: $HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$

acid base water salt

Objectives:

- ◊ Be able to identify acid base neutralization reactions
- ◊ Be able to **predict the products** of the reaction based on ion charges (water + salt)
- ◊ Balance acid base reactions (Tip: balance water as a separate H and OH)

10.8 Single Replacement Reactions $M + AX \rightarrow MX + A$

Single Replacement: A Reaction where a metal replaces a cation in an ionic compound or acid. The metal has to be more active than the cation for the reaction to occur. Thus you have to understand the activity series.

Example: $3\ Mg(s) + 2\ FeBr_3(aq) \rightarrow 3\ MgBr_2(aq) + 2\ Fe(s)$

(Mg is more active than Fe)

Activity Series: Relative order of metal elements and hydrogen arranged by their ability to undergo reaction.

Li > K > Ba > Sr > Ca > Na > Mg > Al > Mn > Zn >

Fe > Cd > Co > Ni > Sn > Pb > (H) > Cu > Ag > Au

⇒ *Note: The Activity Series will be given to you on quizzes and exams*

- Most active (closest to Li) wants to be a cation (+ charged) in a compound with a buddy such as LiCl or $LiNO_3$. The more active metal wants to be social and have a friend.
- Least active (closest to Au) wants to be alone as a neutral element with zero charge such as Au(s) or Ag(s). The least active metal is not as social so wants to be alone.

Objectives:

◊ Be able to identify single-replacement reactions
◊ Be able to **predict the products** of the reaction using the activity series, write the formulas based on charges of the ions
◊ Balance single replacement reactions

Steps to writing single replacement reactions:

1. Check the **Activity Series** to see which metal (or H) ***is more active***.
2. Most active wants to be in a compound, if it is already then there is no reaction, NR, if it is not then switch partners
3. Write the correct product formulas based on ion charges if a reaction occurs
4. Write the states for the products (s, l, g, aq)
5. Balance the equation is always last

YouTube Video on [Steps for Single Replacement Reactions]

Example: Predict the products for Zn(s) + HCl(aq) → ???

1. Check the activity series between Zn and H. Find out that Zn is more active than H.
2. Thus the Zn wants to have a friend. Note that metals bond with negatively charged nonmetals. Thus the friend will be Cl and not H because Cl is -1 charged as an ion.
3. Write the products based on charges → $ZnCl_2$ + H_2 (Zn is +2 and Cl is -1 thus we need two Cl ions to go with one Zn ion) Also realize that hydrogen is diatomic when alone so it will be H_2.
4. $ZnCl_2$ is soluble according to solubility rules thus gets (aq) and hydrogen is a gas (g)
5. Balance the entire reaction now: Zn(s) + 2 HCl(aq) → $ZnCl_2$(aq) + H_2(g)

YouTube Video on [Single Replacement Reactions 1]

[Single Replacement Reaction 2]

[Single Replacement Reaction 3]

10.8 Double Replacement Reactions $M_1X + M_2Y \rightarrow M_1Y + M_2X$

Double Replacement Reaction: Where two metal cations switch partners. When a solid is formed, it is called a precipitation reaction. A solid product is called a precipitate.

Example: $Na_2CO_3(aq) + BaBr_2(aq) \rightarrow 2\ NaBr(aq) + BaCO_3(s)$

Objectives:

◊ Be able to identify double-replacement/precipitation reactions
◊ Be able to identify the precipitate in the reaction
◊ Be able to **predict the products** and write proper product formulas for them based on ion charges
◊ Be able to balance the reaction

10.9 Redox Reactions

Many single replacement, combination, decomposition and combustion reactions are also redox reactions. Redox is short for reduction and oxidation. Reduction is when an element's charge goes down and oxidation is when an element's charge goes up. Note you can't have reduction without oxidation and vice versa. You can't have one without the other in other words.

Example: $Zn(s) + CuCl_2(aq) \rightarrow Cu(s) + ZnCl_2(aq)$

Objectives:

◊ Be able to identify which element's charge goes up or down
◊ Be able to identify what is reduced and what is oxidized

To discover whether a charge is going up or down we need to review ionic charges:

- An element in its natural state or elemental state (i.e. by itself) has a charge of 0.
  - For $H_2(g)$, the charge for H = 0. For Na(s), the charge for Na is 0. Ag(s), Cu(s), $P_4(s)$ and $N_2(g)$ are all charge = zero.
- In a compound, the sum of all charges must equal 0.
  - In Na_3N, the charge for Na is +1 and N is –3. In Al_2O_3, the charge for Al is +3 and O is –2. In PbO_2 the charge for Pb is +4 and O is -2.

Definitions:

- Oxidation = charge goes up, electrons are lost (ox = up)
- Reduction = charge goes down, electrons are gained (reduced = down)

When you are asked what is oxidized or reduced, answer the atom/ion that is involved and which compound it is in, including the state.

Example: $SnCl_2$ (aq) + Zn(s) → Sn(s) + $ZnCl_2$ (aq)

Charge: +2 -1 0 0 +2 -1

What is oxidized? Zn(s) cause its charge goes up from zero to +2

What is reduced? Sn^{2+} in $SnCl_2$ cause its charge goes down from +2 to zero

CHAPTER SUMMARY

•Know how to use solubility rules and the activity series
•Recognize and balance
- –Combination
- –Decomposition

•Recognize, **write products**, and balance
- –Combustion
- –Acid base neutralization
- –Single replacement
- –Double replacement - precipitation

•Identify what is oxidized and reduced in a redox reaction

You Tube Videoes on Predicting Products 1

Predicting Products 2

Predicting Products 3

Practice Problems – Answers follow

I. Examples: Classify and balance the following reactions. If the products are missing, predict them making sure you write proper formulas based on ion charges.

1. ____ K (s) + ____ Br_2 (l) → __ KBr (s)

2. ____ HCl (aq) + ____ NaOH (aq) → ____

3. _____ Al (s) + __ O_2 (g) → __ Al_2O_3 (s)

4. _____ $Al_2(SO_4)_3$ (aq) + __ $BaCl_2$ (aq) → ______________________________

5. _____Li (s) + _____ Cl_2 (g) $\xrightarrow{\Delta}$ ___ LiCl (s)

6. ___ Mg (s) + _____ P_4 (s) $\xrightarrow{\Delta}$ ___ Mg_3P_2 (s)

7. _____ H_2SO_4 (aq) + _____ KOH (aq) → ______________________________

8. ______ Mg (s) + ______ HCl (aq) → ______________________________

9. _____ $KClO_3$ (s) → ___ KCl (s) + _____ O_2 (g)

10. _____ $MgSO_4$(aq) + ___ NaOH(aq) → ______________________________

11. ______ Al (s) + ______ $ZnCl_2$ (aq) → ______________________________

12. _____ $Al(HCO_3)_3$(s) $\xrightarrow{\Delta}$ _____ $Al_2(CO_3)_3$(s) + _____ H_2O(l) + _____ CO_2(g)

13. _____ C_3H_8 (g) + _____ O_2 (g) $\xrightarrow{\Delta}$ ______________________________

14. _____ C_5H_{12} (l) + _____ O_2 (g) $\xrightarrow{\Delta}$ ______________________________

15. ______ Al (s) + ______ HBr (aq) → ______________________________

16. _____ $CaBr_2$ (aq) + ___ $AgNO_3$ (aq) → ______________________________

17. _____ C_6H_6 (l) + _____ O_2 (g) $\xrightarrow{\Delta}$ ______________________________

18. ______ Zn (s) + ______ $AgNO_3$ (aq) → ______________________________

19. _____ $HC_2H_3O_2$ (aq) + _____ $Ca(OH)_2$ (aq) → ______________________________

20. _____ K_2S (aq) + _____ $Pb(NO_3)_2$ (aq) → _____ PbS (s) + _____ KNO_3 (aq)

21. ______ Cu (s) + ______ HCl (aq) → ______________________________

22. ___ $Ca(NO_3)_2$ (aq) + ___ K_3PO_4 (aq) → ______________________________

23. ______ Ag (s) + ______ $Al(NO_3)_3$ (aq) → ______________________________

24. _____ H_3PO_4 (aq) + _____ $Ba(OH)_2$ (aq) → ______________________________

II. Example: Use the Solubility Rules to determine the physical state when the following compounds are placed in water:

- If the compound is **soluble**, indicate the physical state as **(aq)**.
- If the compound is **insoluble**, indicate the physical state as **(s)**.$CaCl_2$

a. Li_2CrO_4

b. $PbBr_2$

c. K_2CO_3

d. $Sr(OH)_2$

e. BaS

f. $Al(OH)_3$

g. Ag_3PO_4

h. Na_2S

III. Example: Give the charge for the following:

1. Mg(s)
2. N_2(g)
3. N in K_3N
4. S in H_2S
5. Br_2(l)
6. Cu in $CuCl_2$

IV. Example: For each of the following redox reactions,

1. Determine charge for each atom
2. Identify the reactant oxidized and the reactant reduced.

a. $Zn\ (s) + HBr\ (aq) \rightarrow H_2\ (g) + ZnBr_2\ (aq)$

The reactant oxidized is ____________.

The reactant reduced is ____________.

b. $Al\ (s) + CdCl_2\ (aq) \rightarrow Cd\ (s) + AlCl_3\ (aq)$

The reactant oxidized is ____________.

The reactant reduced is ____________.

c. Li (s) + S (s) → Li_2S (s)

The reactant oxidized is ___________.

The reactant reduced is ___________.

d. Zn (s) + $CuCl_2$ (aq) → Cu (s) + $ZnCl_2$ (aq)

The reactant oxidized is ___________.

The reactant reduced is ___________.

V. Example: Write and balance these reactions:

a. Hydrogen gas and oxygen gas react to form water.

b. Sodium metal reacts with chlorine gas to produce solid sodium chloride.

c. Zinc metal reacts with hydrochloric acid to produce hydrogen gas and aqueous zinc chloride.

Answers

I. C = combination, D = decomposition, CB = combustion, SR = single replacement, DR = double replacement precipitation, N = neutralization

1. **C**__ 2 K (s) + 1 Br_2 (l) → 2 KBr (s)
2. **N**____ HCl (aq) + ____ NaOH (aq) → H_2O (l) + NaCl (aq)
3. **C**__ 4 Al (s) + 3 O_2 (g) → 2 Al_2O_3 (s)
4. **DR**____ 1 $Al_2(SO_4)_3$ (aq) + 3 $BaCl_2$ (aq) → 3 $BaSO_4$ (s) + 2 $AlCl_3$ (aq)
5. **C**___2 Li (s) + 1 Cl_2 (g) $\xrightarrow{\Delta}$ 2 LiCl (s)
6. **C**___ 6 Mg (s) + 1 P_4 (s) $\xrightarrow{\Delta}$ 2 Mg_3P_2 (s)
7. **N**____ H_2SO_4 (aq) + 2 KOH (aq) → 2 H_2O (l) + K_2SO_4 (aq)
8. **SR**_____ Mg (s) + 2 HCl (aq) → $MgCl_2$ (aq) + **H_2 (g)**
9. **D**___ 2 $KClO_3$ (s) → 2 KCl (s) + 3 O_2 (g)
10. **DR**____ $MgSO_4$(aq) + 2 NaOH(aq) → Na_2SO_4(aq) + $Mg(OH)_2$(s)
11. **SR**_____ 2 Al (s) + 3 $ZnCl_2$ (aq) → 2 **$AlCl_3$ (aq)** + 3 **Zn (s)**

12. **D**____ 2 $Al(HCO_3)_3(s)$ $\xrightarrow{\Delta}$ 1 $Al_2(CO_3)_3(s)$ + 3 $H_2O(l)$ + 3 $CO_2(g)$

13. **CB**____ 1 C_3H_8 (g) + 5 O_2 (g) $\xrightarrow{\Delta}$ 4 **H_2O (g)** + 3 **CO_2 (g)**

14. **CB**____ 1 C_5H_{12} (l) + 8 O_2 (g) $\xrightarrow{\Delta}$ 6 **H_2O (g)** + 5 **CO_2 (g)**

15. **SR**_____ 2 Al (s) + 6 HBr (aq) → 2 **$AlBr_3$ (aq)** + 3 **H_2 (g)**

16. **DR**____ $CaBr_2$ (aq) + 2 $AgNO_3$ (aq) → 2 AgBr (s) + $Ca(NO_3)_2$ (aq)

17. **CB**___ 2 C_6H_6 (l) + 15 O_2 (g) $\xrightarrow{\Delta}$ 6 **H_2O (g)** + 12 **CO_2 (g)**

18. **SR**____ Zn (s) + 2 $AgNO_3$ (aq) → **$Zn(NO_3)_2$ (aq)** + 2 **Ag (s)**

19. **N**____ 2 $HC_2H_3O_2$ (aq) + ____ $Ca(OH)_2$ (aq) → 2 H_2O (l) + $Ca(C_2H_3O_2)_2$ (aq)

20. _**DR**___ K_2S (aq) + ____ $Pb(NO_3)_2$ (aq) → ____ PbS (s) + 2 KNO_3 (aq)

21. _ **NR** ____ Cu (s) + _____ HCl (aq) → **NR**

22. **DR**___ 3 $Ca(NO_3)_2$ (aq) + 2 K_3PO_4 (aq) → 1 $Ca_3(PO_4)_2$ (s) + 6 KNO_3 (aq)

23. **NR** _____ Ag (s) + _____ $Al(NO_3)_3$ (aq) → **NR**

24. _**N**___ 2 H_3PO_4 (aq) + 3 $Ba(OH)_2$ (aq) → 6 H_2O (l) + $Ba_3(PO_4)_2$ (s)

II. Example: $CaCl_2$**(aq)**.

a. Li_2CrO_4**(aq)**.

b. $PbBr_2$ **(s)**.

c. K_2CO_3 **(aq)**.

d. $Sr(OH)_2$**(aq)**.

e. BaS**(aq)**.

f. $Al(OH)_3$**(s)**.

g. Ag_3PO_4**(s)**.

h. Na_2S**(aq)**.

III. Example:

Mg(s) is zero cause elemental state

N_2(g) is zero cause elemental state

N in K_3N is –3 charged

S in H_2S is –2 charged

Br_2(l) is zero cause elemental state

Cu in $CuCl_2$ is +2 charged cause Cl is –1 and there are two of them

IV. Example

a. $Zn\ (s) + HBr\ (aq) \rightarrow H_2\ (g) + ZnBr_2\ (aq)$

0 +1 -1 0 +2 -1

The reactant oxidized is **__Zn(s)_**

The reactant reduced is **__H^{1+} in HBr(aq)__**

b. $Al\ (s) + CdCl_2\ (aq) \rightarrow Cd\ (s) + AlCl_3\ (aq)$

0 +2 -1 0 +3 -1

The reactant oxidized is **__Al(s)**

The reactant reduced is **__Cd^{2+} in $CdCl_2$(aq)**

c. $Li\ (s) + S\ (s) \rightarrow Li_2S\ (s)$

0 0 +1 -2

The reactant oxidized is **__Li(s)_**

The reactant reduced is **__S(s)_**

d. $Zn\ (s) + CuCl_2\ (aq) \rightarrow Cu\ (s) + ZnCl_2\ (aq)$

0 +2 -1 0 +2 -1

The reactant oxidized is **__Zn(s)_**

The reactant reduced is **__Cu^{2+} in $CuCl_2$(aq)**

V. Example:

a. $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (l)$

b. $2\ Na\ (s) + Cl_2\ (g) \rightarrow 2\ NaCl\ (s)$

c. $Zn\ (s) + 2\ HCl\ (aq) \rightarrow H_2\ (g) + ZnCl_2\ (aq)$