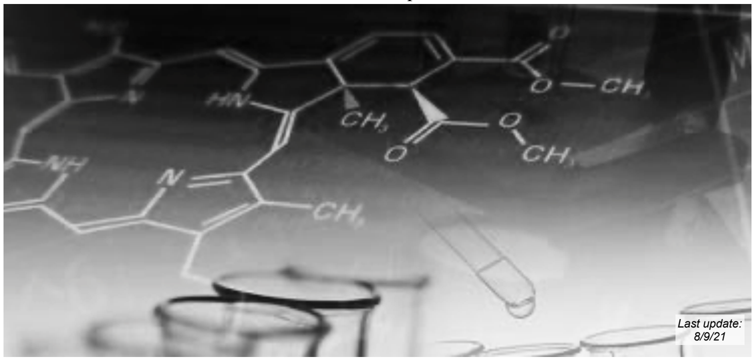
Chemistry 151: Basic Chemistry

Chapter 4 Part I: The Chemical Reaction



Chemical Equations

Chemical equations are like recipes in cooking: They tell a chemist how to make something ("products") and what you'll need to make it ("reactants")

Having balanced amounts critical in cooking: too much flour can make a cake dry, and too little flour can prevent the cake from forming. Same in chemistry!

We will learn how to create a balanced chemical equation in this chapter, and in the next section, we will explore the quantities needed to actually make the products.

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Chemical Equations

Chemical equation: An expression in which symbols and formulas are used to represent a chemical reaction.

Reactant: A substance that undergoes change in a chemical reaction; written on *left side* of the reaction arrow

Product: A substance that is formed in a chemical reaction; written on *right side* of reaction arrow

$$\underbrace{2\,NaHCO_3}_{\text{Reactant}} \xrightarrow{\text{Heat}} \underbrace{Na_2CO_3 + H_2O + CO_2}_{\text{Products}}$$

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Chemical Equations

Equations depict the *kind* of reactants and products and their relative amounts in a reaction.

4 Al(s) + 3 O_2(g) ---> 2 Al_2O_3(s)

The numbers in the front are called

stoichiometric coefficients

The letters (s), (g), (l) and (aq) are the physical states of compounds:

s = solid, g = gas, l = liquid,

aq = solution in water (aqueous)

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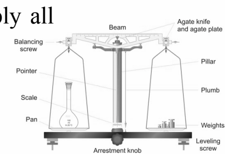
The ***Law of conservation of mass*** states that matter cannot be created or destroyed in any chemical reaction

The bonds between atoms in the reactants are rearranged to form new compounds, but none of the atoms disappear, and no new atoms are formed.

So: Chemical equations must be *balanced*, meaning the numbers and kinds of atoms must be the same on both sides of the reaction arrow.

The numbers placed in front of formulas to balance equations are called *coefficients*, and they multiply all the atoms in the chemical formula.



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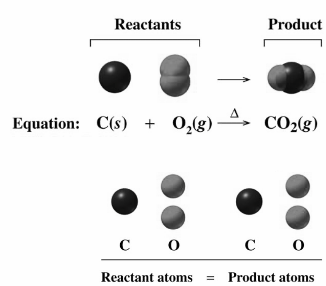
Chemical Equations are Balanced

In a **balanced chemical reaction:**

- atoms are not gained or lost.
- the number of reactant atoms is equal to the number of product atoms.



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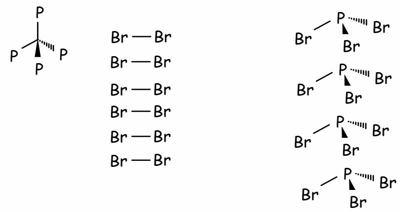
$P_4 + 6\ Br_2 \longrightarrow 4\ PBr_3$



Balance Sheet:

4 P + 12 Br ⟶ 4 P + 12 Br

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Balancing Chemical Equations

The following four steps can be used as a guide to balance chemical equations.

Example: Sulfuric acid reacts with sodium hydroxide to create sodium sulfate and water. Balance this chemical reaction.

Step 1: Write an unbalanced equation, using correct formulas for all reactants and products.

$H_2SO_4 + NaOH \longrightarrow Na_2SO_4 + H_2O$ (Unbalanced)

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Step 2: Add appropriate coefficients to balance the numbers of atoms of each element.

$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + H_2O$ (Balanced for Na)

Add this coefficient . . . . . . to balance these 2 Na.

$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + H_2O$ (Balanced for Na and sulfate)

One sulfate here . . . . . . and one here.

Step 3: Check the equation to make sure the numbers and kinds of atoms on both sides of the equation are same.

$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O$ (Completely balanced)

4 H and 2 O here. 4 H and 2 O here.

Step 4: Make sure the coefficients are reduced to their lowest whole-number value (ok here).

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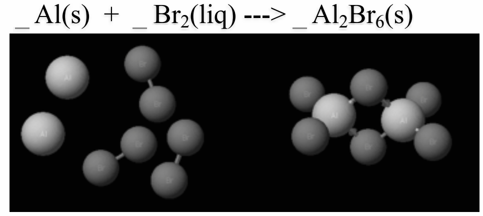
Balancing Equations

_ Al(s) + _ Br_2(liq) ---> _ Al_2Br_6(s)



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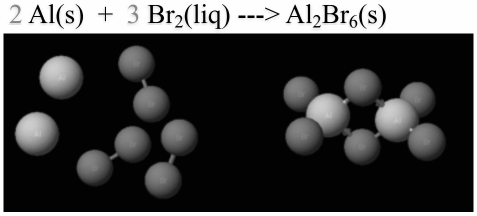
Balancing Equations

2 Al(s) + 3 Br_2(liq) ---> Al_2Br_6(s)



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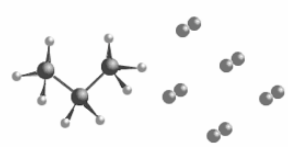

Balancing Equations

____C_3H_8(g) + _____ O_2(g) -->

_____CO_2(g) + _____ H_2O(g)

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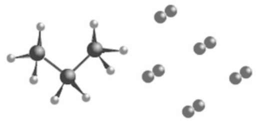

Balancing Equations

$C_3H_8(g)$ + 5 $O_2(g)$ ---->
3 $CO_2(g)$ + 4 $H_2O(g)$

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Balancing Equations

Balance the following:
Calcium + nitrogen → Calcium nitride

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Balancing with Polyatomic Ions

Magnesium chloride + sodium phosphate →
magnesium phosphate + sodium chloride

$MgCl_2(aq) + Na_3PO_4(aq) \rightarrow NaCl(aq) + Mg_3(PO_4)_2(s)$

Leave polyatomic ions as "units", don't break up when balancing, usually balance them first before other atoms

$MgCl_2(aq) + 2Na_3PO_4(aq) \rightarrow NaCl(aq) + Mg_3(PO_4)_2(s)$

$3MgCl_2(aq) + 2Na_3PO_4(aq) \rightarrow 6NaCl(aq) + Mg_3(PO_4)_2(s)$

2 PO_4^{3-}	=	2 PO_4^{3-}
3 Mg^{2+}	=	3 Mg^{2+}
6 Na^+	=	6 Na^+
6 Cl^-	=	6 Cl^-

Balanced!

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Balancing Equations

Balance the following. To save time, balance polyatomic ions as units (not individual atoms):

$BaCl_2 + Na_3PO_4 \rightarrow Ba_3(PO_4)_2 + NaCl$

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Balancing Equations - Hints

- Balance those atoms which occur in only one compound on each side
- Balance the remaining atoms
- Reduce coefficients to smallest whole integers
- Check your answer
- *Remember the seven diatomics! HONCl BrIF*

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Test Yourself

Balance the following reactions:

$K_{(s)} + H_2O_{(l)} \rightarrow H_{2(g)} + KOH_{(aq)}$

$Ba_{(s)} + H_3AsO_{4(aq)} \rightarrow H_{2(g)} + Ba_3(AsO_4)_{2(aq)}$

$PCl_{5(s)} + H_2O_{(l)} \rightarrow H_3PO_{4(aq)} + HCl_{(aq)}$

$KClO_{3(s)} \rightarrow KCl_{(s)} + O_{2(g)}$

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practice, practice, practice!

Types of Reactions

Most chemical reactions can be grouped into one of these six categories:

1. **Combination** A + B → AB
2. **Decomposition** AB → A + B
3. **Single Replacement** AB + C → CB + A *or* MY + X → MX + Y

(Metals replace metals; nonmetals replace nonmetals)

4. **Combustion** $C_xH_y + O_2 \rightarrow CO_2 + H_2O$
5. **Acid-Base** $HX + MOH \rightarrow MX + H_2O$
6. **Precipitation** $AX + BY \rightarrow AY(s) + BX$

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Combination (Addition)

In a **combination reaction**, two or more reactants form one product or simple compounds combine to form one product.

A + B ⟶ AB

$2\ Mg(s) + O_2(g) \longrightarrow 2\ MgO(s)$

$2\ Na(s) + Cl_2(g) \longrightarrow 2\ NaCl(s)$

$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$

Combination reactions are also known as **addition reactions.**

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Decomposition

In a **decomposition reaction**, one substance splits into two or more simpler substances.

A reactant	splits into	two or more products
AB	⟶	A + B

$2\ HgO(s) \longrightarrow 2\ Hg(l) + O_2(g)$

$2\ KClO_3(s) \longrightarrow 2\ KCl(s) + 3\ O_2(g)$

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Learning Check

Classify the following reactions as combination or decomposition.

$H_2(g) + Br_2(g) \longrightarrow 2\ HBr(l)$ *Combination*

$Al_2(CO_3)_3(s) \longrightarrow Al_2O_3(s) + 3\ CO_2(g)$ *Decomposition*

$4\ Al(s) + 3\ C(s) \longrightarrow Al_4C_3(s)$ *Combination*

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Single Replacement Reactions

Single replacement reactions:

$$A + BC \rightarrow AC + B$$
$$X + BY \rightarrow BX + Y$$

Metal (A and B) replace metals;
Non-metals (X and Y) replace non-metals

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Single Replacement

In a **single replacement** reaction, one element takes the place of a different element in a reacting compound.

Single replacement

One element	replaces	another element
A + BC	⟶	AC + B

Metals (Zn and Ag) replacing metals:

$Zn(s) + 2\ AgCl(aq) \longrightarrow ZnCl_2(aq) + 2\ Ag(s)$

Nonmetals (Br and Cl) replacing nonmetals:

$Br_2(g) + 2\ NaCl(aq) \longrightarrow 2\ NaBr(aq) + Cl_2(g)$

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Learning Check

Complete and balance the following single replacement equation:

Metals replace metals:
zinc + silver nitrate →

Non-metals replace non-metals:
chlorine + sodium iodide →

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Combustion Reactions

In a combustion reaction, a hydrocarbon (containing C, H and/or O) reacts with oxygen (O_2) to make carbon dioxide and water. These are very common in organic chemistry (and in your combustion gasoline car!)

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

$$C_6H_{12}(g) + 9\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(g)$$

$$2\ C_2H_4O(g) + 5\ O_2(g) \rightarrow 4\ CO_2(g) + 4\ H_2O(g)$$

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Acid-Base Reactions

In an acid-base reaction, an acid (H listed first) reacts with a base (metal hydroxide) to create water and a "salt"

Double replacement

Two elements **replace each other**

A B + C D → A D + C B

$HNO_3(aq) + NaOH(aq) \longrightarrow H_2O(l) + NaNO_3(aq)$
acid *base* *water* *salt*

Acid-Base reactions are also a type of **double displacement** or **exchange reactions**

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Acid-Base Reactions

When equal amounts (moles) of acids (H^+) and bases (OH^-) are mixed together, both acidic and basic properties disappear because of a neutralization reaction. The neutralization reaction produces water and a salt.

Example: $HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$
acid *base* *water* *salt*

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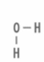
Acid-Base Reactions

Example: $HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$
acid *base* *water* *salt*



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Precipitation Reactions

In a precipitation reaction, reactants exchange cations, and at least one of the products is a solid (a *precipitate*)

Double replacement

Two elements **replace each other**

A B + C D → A D + C B

$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$
precipitate

Precipitation reactions are also a type of **double displacement** or **exchange reactions**

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Precipitation Reactions

Solubility: The amount of a compound that will dissolve in a given amount of solvent at a given temperature.

When solubility exceeded, precipitates form

$Pb(NO_3)_2(aq) + 2\ KI(aq) \rightarrow PbI_2(s) + 2\ KNO_3(aq)$

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Test Yourself

Balance and classify the following reactions:

$C_5H_{12}(l) + O_2(g) \rightarrow$

$HCl(aq) + Pb(NO_3)_2(aq) \rightarrow$ *$PbCl_2(s)$ is a product*

$HI(aq) + LiOH(aq) \rightarrow$

practice, practice, practice!

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End of Chapter 4 Part I