Chemistry deals with matter and its changes

CHEMICAL REACTIONS
CHEMICAL EQUATIONS

\[ \text{N}_2 + 3 \text{H}_2 \rightarrow 2 \text{NH}_3 \]

reactants

\[
\begin{align*}
2 \text{N} & \quad 6 \text{H} \\
\text{products} & \quad 2 \text{N} \\
& \quad 6 \text{H}
\end{align*}
\]

balanced means equal numbers of atoms of each element on each side

When reactants and products are given, only need to change coefficients to achieve balance
COMPLETE COMBUSTION

Hydrocarbon or other fuel combines with O₂ to produce CO₂ and water.

**EXAMPLE:**

Propane C₃H₈ in a barbeque grill

\[ \text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O} \]

\[
\begin{align*}
3\text{C} & = 3\text{C} \\
8\text{H} & = 8\text{H} \\
10\text{O} & = 6\text{O} + 4\text{O}
\end{align*}
\]
STEPS TO BALANCE A CHEMICAL EQUATION

(1) Write an unbalanced equation containing the correct formulas of the reactants and products.
(2) Balance atoms of one of the elements.
(3) Balance atoms of the remaining elements.
(4) Verify that the number of atoms of each element is balanced.
EXAMPLE: destruction of marble by acid rain

Begin with unbalanced equation

\[ \text{HNO}_3(aq) + \text{CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{Ca(NO}_3)_2(aq) \]

• focus on N to get

\[ 2 \text{HNO}_3(aq) + \text{CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{1 Ca(NO}_3)_2(aq) \]

• next, focus on Ca to get

\[ 2 \text{HNO}_3(aq) + \text{CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{1 Ca(NO}_3)_2(aq) \]

• focus on H: 2 on left, so we get

\[ 2 \text{HNO}_3(aq) + \text{1 CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{1 H}_2\text{O}(l) + \text{1 Ca(NO}_3)_2(aq) \]

• left is finished, and it has 1 C so we get

\[ 2 \text{HNO}_3(aq) + \text{1 CaCO}_3(s) \rightarrow \text{1 CO}_2(g) + \text{1 H}_2\text{O}(l) + \text{1 Ca(NO}_3)_2(aq) \]

• Is O balanced?
  left: 6 + 3 = 9  right: 2 + 1 + 6 = 9

• the final result is:

\[ 2 \text{HNO}_3(aq) + \text{CaCO}_3(s) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{Ca(NO}_3)_2(aq) \]
EQUATIONS TO BALANCE

\[ \text{H}_2\text{S(aq)} + \text{Cl}_2(\text{aq}) \rightarrow \text{S}_8(\text{s}) + \text{HCl(\text{aq})} \]

\[ \text{CaO(s)} + \text{NH}_4\text{Cl(s)} \rightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{O(g)} + \text{CaCl}_2(\text{s}) \]

\[ \text{Al(OH)}_3(\text{s}) + \text{HCl(\text{aq})} \rightarrow \text{AlCl}_3(\text{aq}) + \text{H}_2\text{O(\ell)} \]
REACTION TYPES

COMBINATION

elements react to form compounds

\[ S(s) + O_2(g) \rightarrow SO_2(g) \]

small compounds combine to make larger ones

\[ CaO(aq) + CO_2(g) \rightarrow CaCO_3(s) \]

DECOMPOSITION

\[ 2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2 \]
\[ \text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2 \]

COMBUSTION

organic compound + O\textsubscript{2}

\[ \text{C}_2\text{H}_5\text{OH(l)} + 3 \text{O}_2 \rightarrow 2 \text{CO}_2 + 3 \text{H}_2\text{O} \]
REACTION TYPES

SINGLE DISPLACEMENT

one element replaces another

CuSO$_4$(aq) + Zn(s) $\rightarrow$ ZnSO$_4$(aq) + Cu(s)

DOUBLE DISPLACEMENT

ions or atoms exchange

Precipitation

CaCl$_2$(aq) + 2 AgNO$_3$(aq) $\rightarrow$ 2 AgCl(s) + Ca(NO$_3$)$_2$ (aq)

Acid-Base Reaction

HNO$_3$ + KOH $\rightarrow$ H$_2$O + KNO$_3$

acid     base     water     salt
EXCHANGE REACTIONS

Double displacement
Require a driving force
Three driving forces:

1. Precipitate forms
2. Gas forms
3. Weak or non-electrolyte forms
   (molecular species)

\[ AX + BY \rightarrow AB + XY \]
Mix Pb(NO₃)₂ and KI.....what happens?

\[
Pb(NO₃)_2 (aq) + 2 KI(aq) \rightarrow PbI₂(s) + 2 KNO₃(aq)
\]

**Complete ionic equation**

\[
Pb²⁺(aq) + 2 NO₃⁻(aq) + 2 K⁺(aq) + 2 I⁻(aq) \rightarrow PbI₂(s) + 2 NO₃⁻(aq) + 2 K⁺(aq)
\]

**Eliminate spectator ions**

**Net ionic equation**

\[
Pb²⁺(aq) + 2 I⁻(aq) \rightarrow PbI₂(s)
\]
The ions comprising an ionic compound determine its solubility

**Simplified Rules:**

1. Almost all ammonium and alkali metal salts are soluble.
2. Most nitrates, acetates, chlorides, bromides, iodides, and sulfates are soluble. Important exceptions are silver halides, and Ca, Ba, Pb sulfates.
3. Most sulfides, carbonates, phosphates, and hydroxides are insoluble. Important exceptions are the alkali and ammonium salts.
IONIC EQUATIONS

acid-base neutralization example
HNO₃(aq) + KOH(aq) → H₂O(ℓ) + KNO₃(aq)

H⁺(aq) + NO₃⁻(aq) + K⁺(aq) + OH⁻(aq) → H₂O(ℓ) + NO₃⁻(aq) + K⁺(aq)

spectator ions

net ionic equation
H⁺(aq) + OH⁻(aq) → H₂O(ℓ)

precipitation reaction example
AgNO₃(aq) + NaCl(aq) → AgCl(s) + NaNO₃(aq)

Ag⁺(aq) + NO₃⁻(aq) + Na⁺(aq) + Cl⁻(aq) → AgCl(s) + NO₃⁻(aq) + Na⁺(aq)

net ionic equation
Ag⁺(aq) + Cl⁻(aq) → AgCl(s)
direct production of gas
- or -
production of weak acid which decomposes

example: $H_2CO_3$

$HCl(aq) + NaHCO_3(aq) \rightarrow NaCl(aq) + H_2CO_3(aq)$

sodium bicarbonate

$H_2O(\ell) + CO_2(g)$

net ionic equation

$H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(\ell) + CO_2(g)$
**ACIDS-BASE NEUTRALIZATION**

ACID + BASE $\rightarrow$ SALT + WATER

HNO$_3$ + KOH $\rightarrow$ KNO$_3$ + H$_2$O

**complete ionic equation**

$\text H^+(\text{aq}) + \text{NO}_3^-(\text{aq}) + \text K^+(\text{aq}) + \text OH^-(\text{aq}) \rightarrow \text H_2\text O(\text{l}) + \text K^+(\text{aq}) + \text{NO}_3^-(\text{aq})$

eliminate spectator ions

**net ionic equation**

$\text H^+(\text{aq}) + \text OH^-(\text{aq}) \rightarrow \text H_2\text O(\text{l})$
ACIDS, BASES, SALTS

They are electrolytes: (strong or weak)

ACIDS

Donate hydrogen ion $H^+(aq), H_3O^+(aq)$

$\text{HNO}_3(aq) \rightarrow H^+(aq) + \text{NO}_3^-(aq)$

BASES

Accept hydrogen ion
Raise conc. of $\text{OH}^-(aq)$ ions

$\text{KOH}(aq) \rightarrow \text{K}^+(aq) + \text{OH}^-(aq)$

SALTS

Ionic compounds
Replace $H^+$ of acid with positive ion

$\text{HNO}_3$ becomes $\text{KNO}_3$
### Strong Acids and Bases

#### Table 4.2

**Strong Acids**

<table>
<thead>
<tr>
<th>Acid Type</th>
<th>Acid Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric</td>
<td>HCl</td>
<td></td>
</tr>
<tr>
<td>Hydrobromic</td>
<td>HBr</td>
<td></td>
</tr>
<tr>
<td>Hydroiodic</td>
<td>HI</td>
<td></td>
</tr>
<tr>
<td>Chloric</td>
<td>HClO₃</td>
<td></td>
</tr>
<tr>
<td>Perchloric</td>
<td>HClO₄</td>
<td></td>
</tr>
<tr>
<td>Nitric</td>
<td>HNO₃</td>
<td></td>
</tr>
<tr>
<td>Sulfuric</td>
<td>HSO₄</td>
<td></td>
</tr>
</tbody>
</table>

**Strong Bases**

- Group 1A metal hydroxides: LiOH, NaOH, KOH, RbOH, CsOH
- Heavy Group IIA metal hydroxides: Ca(OH)₂, Sr(OH)₂, Ba(OH)₂
REDOX REACTIONS

Reactions where electrons are transferred from one reactant to another.

Reduction reaction: \[ X_2 + 2 \text{ e}^- \rightarrow 2 X^- \]

Oxidation reaction: \[ M \rightarrow M^{n+} + n \text{ e}^- \]

reduction = accepting e\(^-\)
oxidation = losing e\(^-\)

The two processes are always linked.
OXIDIZING AGENTS

O₂, halogens, H₂O₂, HNO₃,
Cr₂O₇⁻, MnO₄⁻

REDUCING AGENTS

H₂, C, metals
OXIDATION NUMBERS

Oxidation numbers always change in redox reactions

Example: acid displacement reaction

\[
\text{Mg(s) + 2 HCl(aq) } \rightarrow \text{ MgCl}_2(aq) + \text{ H}_2(g)
\]

<table>
<thead>
<tr>
<th></th>
<th>Mg</th>
<th>0</th>
<th>+1</th>
<th>-1</th>
<th>+2</th>
<th>-1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1</td>
<td>→ 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>no change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OXIDATION NUMBERS

How to determine oxidation numbers

(1) The oxid. no. of an atom of a pure element is 0.
(2) The oxid. no. of a monatomic ion equals its charge.
(3) Some elements have the same oxid. no. in almost all of their compounds and can be used as references for oxid. nos. of other elements in compounds.
(4) The sum of the oxid. nos. in a neutral compound is 0; the sum of the oxid. nos. in a polyatomic ion equals the charge on the ion.
Relative reactivity of metals lead to the activity series

A metal higher in the series will always displace an element below it

Metals above H₂ in series will displace it from acid such as HCl to form H₂ (Mg, Zn, Fe)

Metals toward bottom are unreactive (Ag, Pt, Au)
REACTIONS OF METALS WITH ACIDS

FOR MANY METALS

metal + acid → salt + H₂

Fe(s) + H₂SO₄(aq) → FeSO₄(aq) + H₂(g)

SINGLE DISPLACEMENT

A + BX → AX + B

metal → acid or metal salt

the metal is oxidized
USING A BALANCED CHEMICAL EQUATION QUANTITATIVELY

Use molar mass to convert

moles $\rightarrow$ grams
grams $\rightarrow$ moles

Use balanced equation to convert

moles reactant $\rightarrow$ moles product
moles product $\rightarrow$ moles reactant
(Not Balanced) \( \text{Pb(NO}_3\text{)}_2 + \text{KI} \rightarrow \text{PbI}_2 + \text{KNO}_3 \)

(Balanced) \( \text{Pb(NO}_3\text{)}_2 + 2 \text{KI} \rightarrow \text{PbI}_2 ↓ + 2 \text{KNO}_3 \)

2 mol KI reacts with 1 mol \( \text{Pb(NO}_3\text{)}_2 \)

MW of \( \text{Pb(NO}_3\text{)}_2 \) | MW of KI
---|---
Pb 207.2 | K 39.1
N 2 x 14 = 28. | I 126.9
O 6 x 16 = 96. | \( \underline{166.0 \text{ g/mol}} \)
331.2 g/mol | 2 mol = 332.0 g

So, 331.2 g \( \text{Pb(NO}_3\text{)}_2 \) reacts completely with 332.0 g of KI
An iron atom weighs roughly twice as much as a sulfur atom. If you want to prepare the compound FeS in a quantitative reaction, approximately what quantities of Fe and S do you combine in the lab?

1. Equal masses of Fe and S?
2. Twice as much Fe as S?
3. Twice as much S as Fe?
NITROGLYCERINE DECOMPOSITION

\[ 4 \text{C}_3\text{H}_5(\text{NO}_3)_3(\ell) \rightarrow \]
\[ 12 \text{CO}_2(\text{g}) + 10 \text{H}_2\text{O}(\text{g}) + 6 \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \]

How much gas is produced per g of nitroglycerine?
HOW MUCH CO$_2$ DOES YOUR CAR PRODUCE?

Assume gasoline is octane C$_8$H$_{18}$

$$2 \text{ C}_8\text{H}_{18} + 25 \text{ O}_2 \rightarrow 16 \text{ CO}_2 + 18 \text{ H}_2\text{O}$$

1 gal = \(\frac{4 \text{ qt}}{1.057 \text{ qt/L}}\) = 3.78 L

Assume density of 0.80 g/mL

3.78 L x 0.80 g/mL x 10$^3$ mL/L = 3.02 x 10$^3$ g octane

$$\frac{3020 \text{ g}}{114 \text{ g/mol}} = 26.4 \text{ mol octane in 1 gal}$$

2 mol octane \(\rightarrow\) 16 mol CO$_2$

26.4 mol octane \(\rightarrow\) 211 mol CO$_2$

211 mol CO$_2$ x 44 g/mol = 9280 g CO$_2$

1 gal octane \(\rightarrow\) 9.3 kg CO$_2$

(6.7 lb) \(\rightarrow\) (20.5 lb)

10,000 mi/year at 25 mpg = 400 gal/year

400 gal octane \(\rightarrow\) 8200 lb or 4 tons CO$_2$
LIMITING REACTANT

• The limiting reactant is used up first
• The limiting reactant determines the amount of product
• Need balanced equation to proceed
Limiting Reagents

2H₂ + O₂ → 2H₂O

10 H₂ and 7 O₂ → 10 H₂O and 2 O₂

reaction stops when one of the reactants is depleted

What if you had only 220.0 g Pb(NO₃)₂? How much PbI₂ would precipitate?
STOICHIOMETRY EXAMPLE

(Not Balanced) \[ \text{Pb(NO}_3\text{)}_2 + \text{KI} \rightarrow \text{PbI}_2 + \text{KNO}_3 \]

(Balanced) \[ \text{Pb(NO}_3\text{)}_2 + 2 \text{ KI} \rightarrow \text{PbI}_2 \downarrow + 2 \text{ KNO}_3 \]

2 mol KI reacts with 1 mol Pb(NO$_3$)$_2$

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So, 331.2 g Pb(NO$_3$)$_2$ reacts completely with 332.0 g of KI
LIMITING REACTANT

EXAMPLE

If 18.3 g of C₂H₅OH reacts with 63.8 g of O₂ (combustion), how many g of CO₂ are produced?

Need balanced equation to start

Combustion:

C₂H₅OH + 3 O₂ → 2 CO₂ + 3 H₂O
C₂H₅OH + 3 O₂ → 2 CO₂ + 3 H₂O

18.3 g          63.8 g          ? g

To find limiting reactant, first need MWs

C₂H₅OH        O₂

2 x 12 = 24    2 x 16 = 32 g/mol
1 x 16 = 16
6 x 1 = 6

46 g/mol

Need moles of reactants

C₂H₅OH  O₂

\[
\frac{18.3 \text{ g}}{46 \text{ g/mol}} = 0.398 \text{ mol} \quad \frac{63.8 \text{ g}}{32 \text{ g/mol}} = 1.99 \text{ mol}
\]
LIMITING REACTANT cont.

Now, knowing the LR, find the final answer.

1 mol $\text{C}_2\text{H}_5\text{OH}$ $\rightarrow$ 2 mol $\text{CO}_2$

0.398 mol $\text{C}_2\text{H}_5\text{OH}$ $\rightarrow$ 0.796 mol $\text{CO}_2$

Need MW of $\text{CO}_2$

\[
\begin{align*}
1 \times 12 &= 12 \\
2 \times 16 &= 32 \\
\text{MW} &= 44 \text{ g/mol}
\end{align*}
\]

\[
(0.796 \text{ mol}) (44 \text{ g/mol}) = 35.0 \text{ g} \text{ CO}_2
\]
Lithium oxide is used on the space shuttle to remove water from the air

\[ \text{Li}_2\text{O}(s) + \text{H}_2\text{O}(g) \rightarrow 2 \text{LiOH}(s) \]

Which reactant is limiting if 100.0 kg of water is to be removed and 82.0 kg of Li\(_2\)O is present?

How much product is formed?

Need moles of reactants

\[
\begin{align*}
\text{Li}_2\text{O} & \quad 82.0 \text{ kg} \times 10^3 \text{ g/kg} \times \frac{1 \text{ mol}}{29.88 \text{ g}} = 2744 \text{ mol} \\
\text{H}_2\text{O} & \quad 100.0 \text{ kg} \times 10^3 \text{ g/kg} \times \frac{1 \text{ mol}}{18.01 \text{ g}} = 5552 \text{ mol}
\end{align*}
\]

Li\(_2\)O will be exhausted first

Moles LiOH = 2 x moles Li\(_2\)O

Moles LiOH = 2 x 2744 = 5488 moles

5488 moles x 23.95 g/mol x 10\(^{-3}\) kg/g = 131.4 kg LiOH