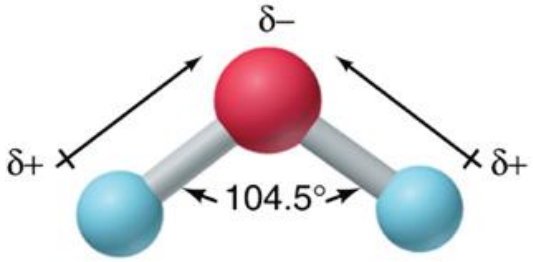
Reactions in Aqueous Solutions

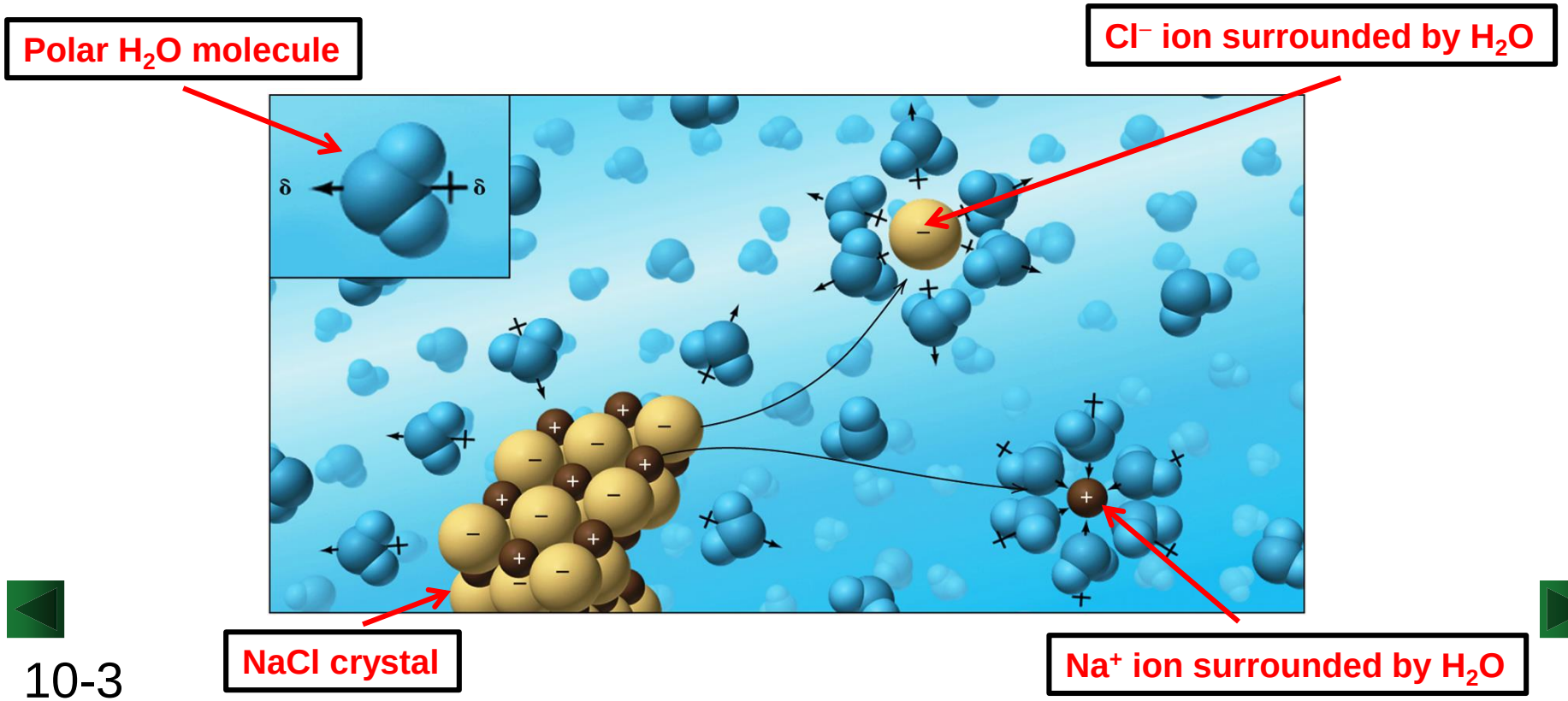
Molarity or Concentration

Water as a Polar Solvent

- Water is a polar molecule
  - since it has uneven electron distribution
  - and a bent molecular shape.



- Due to its polar nature, water interacts strongly with its solutes and often plays an active role in aqueous reactions.



Molarity or Concentration

- The ***concentration*** of a solution is given by the quantity of solute present in a given quantity of solution.

- ***Molarity*** (*M*) is often used to express concentration. It is the number of **moles** of ***solute*** dissolved **per liter** of ***solution***.

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \qquad M = \frac{\text{mol}}{\text{L}}$$

Sample Problem 4.5

What amount (mol) of each ion is in 35 mL of 0.84 *M* zinc chloride?

SOLUTION

$$ZnCl_2(s) \xrightarrow{H_2O} Zn^{2+}(aq) + 2Cl^-(aq)$$

$$\#\text{ moles } ZnCl_2 = M \times V = 0.84M \times \frac{35}{1000} L$$

$$= 0.0294 \text{ moles}$$

0.0294 moles $ZnCl_2$ will produce 0.0294 moles Zn^{2+}

0.0294 moles $ZnCl_2$ will produce $(0.0294 \times 2) = 0.0588$ moles of Cl^-

Sample Problem 4.6

"Isotonic saline" is a 0.15 *M* aqueous solution of NaCl. How many liters of 6.0 *M* stock solution would you need to prepare 0.80 L of isotonic saline?

SOLUTION

moles before dilution = # moles after dilution

$M_1 V_1 = M_2 V_2$

$6.0\,M \times V_1 = 0.15\,M \times 0.80\,L$

$V_1 = \dfrac{0.15\,M \times 0.80\,L}{6.0\,M}$

$= 0.02\,L.$

Total and Net Ionic Equations

Total and Net Ionic Equations

$$2AgNO_3(aq) + Na_2CrO_4(aq) \rightarrow Ag_2CrO_4(s) + 2NaNO_3(aq)$$

- The **total ionic equation** shows all soluble ionic substances *dissociated into ions*.

$$2Ag^+(aq) + 2NO_3^-(aq) + 2Na^+(aq) + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s) + 2Na^+(aq) + 2NO_3^-(aq)$$

- **Spectator ions** are not involved in the actual chemical change. Spectator ions appear unchanged on both sides of the total ionic equation.

$$2Ag^+(aq) + \cancel{2NO_3^-(aq)} + \cancel{2Na^+(aq)} + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s) + \cancel{2Na^+(aq)} + \cancel{2NO_3^-(aq)}$$

- The **net ionic equation** eliminates the ***spectator ions*** and shows only the *actual chemical change*.

$$2Ag^+(aq) + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s)$$

- **Note:** Solid, liquid and gas remain in their same form. They can not be broken down into ions. e.g. $CaCO_3(s)$, $H_2O(l)$, $CO_2(g)$, etc.

Precipitation Reaction

Precipitation Reaction

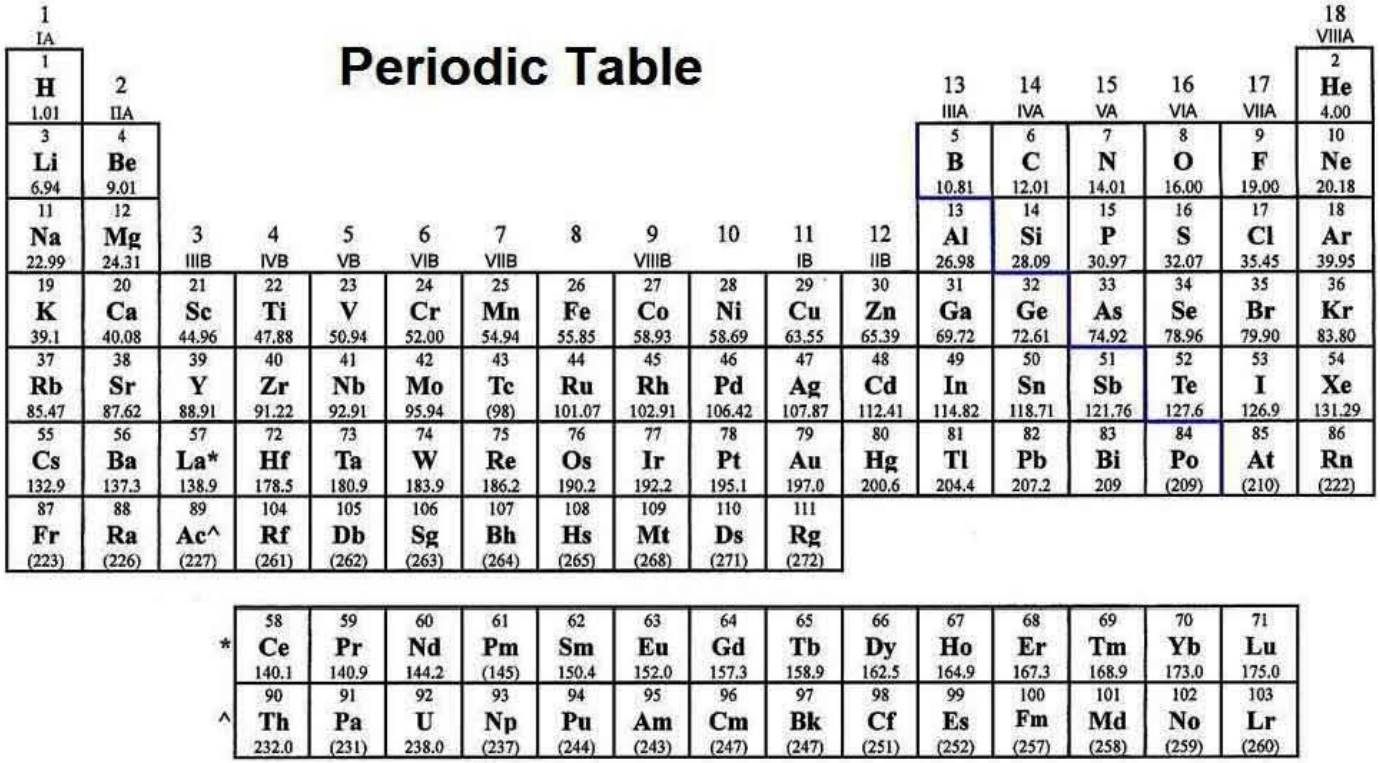
- In a **precipitation reaction** two soluble ionic compounds react to give an insoluble product, called a ***precipitate***.

$$2AgNO_3(aq) + Na_2CrO_4(aq) \rightarrow Ag_2CrO_4(s) + 2NaNO_3(aq)$$

- A **precipitation reaction** is also known as a ***metathesis*** or ***double displacement*** reaction.

SOLUBILITY GUIDELINES

Soluble Ionic Compounds	Insoluble Ionic Compounds
1. Group 1A(1) ions (Li^+, Na^+, K^+, etc.) and ammonium (NH_4^+)	1. OH^- ***except*** with Group 1A(1), NH_4^+, Sr^{2+}, Ba^{2+}, and Ca^{2+}(low solubility)
2. NO_3^-, CH_3COO^-, and ClO_4^-	2. CO_3^{2-} ***except*** with Group 1A(1) and NH_4^+
3. Cl^-, Br^-, I^- ***except*** with Ag^+, Pb^{2+}, Cu^+, and Hg_2^{2+}	3. PO_4^{3-} ***except*** with Group 1A(1) and NH_4^+
4. F^- ***except*** with $Pb^{2+}$and Group 2A(2)	4. S^{2-} ***except*** with Group 1A(1) and NH_4^+
5. SO_4^{2-} ***except*** with Ca^{2+}, Sr^{2+}, Ba^{2+}, Ag^+, and Pb^{2+}	5. $C_2O_4^{2-}$ ***except*** with Group 1A(1) and NH_4^+



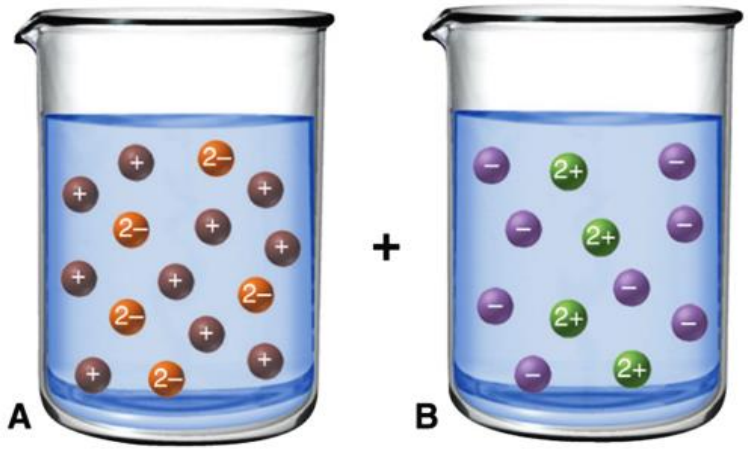
Sample Problem 4.9

The following molecular views show reactant solutions for a precipitation reaction (with H_2O molecules omitted for clarity).

a) Which compound is dissolved in **beaker A**: KCl, Ag_2SO_4, $MgBr_2$, or Na_2SO_4?

b) Which compound is dissolved in **beaker B**: NH_4NO_3, $MgSO_4$, $Ba(NO_3)_2$, or CaF_2?

c) Name the precipitate and spectator ions when solutions A and B are mixed, and write balanced **molecular**, **total ionic**, and **net ion equations** for this process.



SOLUTION

$Na_2SO_4(aq) + Ba(NO_3)_2(aq) \longrightarrow 2\,NaNO_3(aq) + BaSO_4(s)$

Total: $2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2NO_3^-(aq) \longrightarrow 2Na^+(aq) + 2NO_3^-(aq) + BaSO_4(s)$

Net: $SO_4^{2-}(aq) + Ba^{2+}(aq) \longrightarrow BaSO_4(s)$

Acid-Base Neutralization

Acid-Base Neutralization

- An **acid** is a substance that produces H^+ ions when dissolved in H_2O.

$$HX \xrightarrow{H_2O} H^+(aq) + X^-(aq)$$

- A **base** is a substance that produces OH^- ions when dissolved in H_2O.

$$MOH \xrightarrow{H_2O} M^+(aq) + OH^-(aq)$$

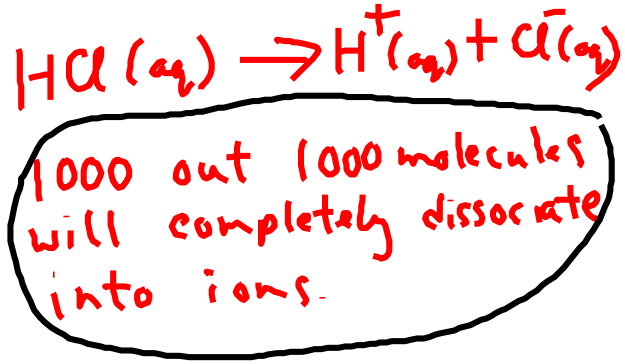
- An **acid-base reaction** is also called a **neutralization** reaction. A **salt** and **water** are produced.

$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$

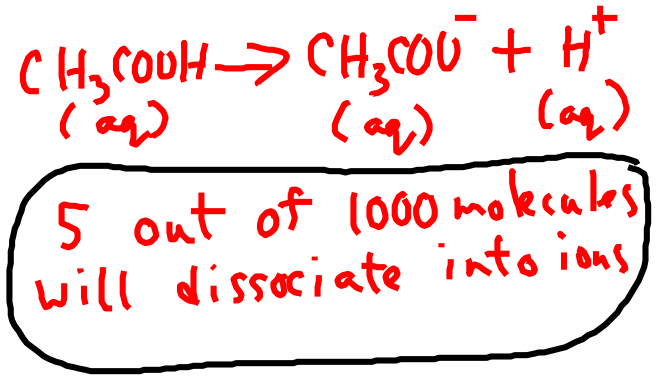
acid base salt water

Net: $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

Strong Acid or **Strong Base**:
Dissociates completely into ions



Weak Acid or **Weak Base**: **Does NOT dissociate completely**



Acids

Strong
Hydrochloric acid, HCl
Hydrobromic acid, HBr
Hydriodic acid, HI
Nitric acid, HNO_3
Sulfuric acid, H_2SO_4
Perchloric acid, $HClO_4$

Weak (a few of many examples)
Hydrofluoric acid, HF
Phosphoric acid, H_3PO_4
Acetic acid, CH_3COOH (or $HC_2H_3O_2$)

Bases

Strong
Group 1A(1) hydroxides:
Lithium hydroxide, LiOH
Sodium hydroxide, NaOH
Potassium hydroxide, KOH
Rubidium hydroxide, RbOH
Cesium hydroxide, CsOH

Heavy Group 2A(2) hydroxides:
Calcium hydroxide, $Ca(OH)_2$
Strontium hydroxide, $Sr(OH)_2$
Barium hydroxide, $Ba(OH)_2$

Weak (one of many examples)
Ammonia, NH_3

Acids and Bases as Electrolytes

Strong acids and strong bases dissociate completely into ions in aqueous solution. They are ***strong electrolytes*** and conduct well in solution.

Weak acids and weak bases dissociate very little into ions in aqueous solution. They are ***weak electrolytes*** and conduct poorly in solution.

Sample Problem 4.14

Write balanced, total and net ionic equations for the following reactions:

a) hydriodic acid (*aq*) + calcium hydroxide (*aq*) →

b) potassium hydroxide (*aq*) + propanoic acid (*aq*) →

SOLUTION

(a) $2HI(aq) + Ca(OH)_2(aq) \longrightarrow CaI_2(aq) + 2H_2O(l)$

Total: $2H^+(aq) + 2I^-(aq) + Ca^{2+}(aq) + 2OH^-(aq) \longrightarrow Ca^{2+}(aq) + 2I^-(aq) + 2H_2O(l)$

Net: $2H^+(aq) + 2OH^-(aq) \longrightarrow 2H_2O(l)$

(b) $KOH(aq) + C_2H_5COOH(aq) \longrightarrow C_2H_5COOK(aq) + H_2O(l)$

Total: $K^+(aq) + OH^-(aq) + C_2H_5COOH(aq) \longrightarrow C_2H_5COO^-(aq) + K^+(aq) + H_2O(l)$

Net: $OH^-(aq) + C_2H_5COOH(aq) \longrightarrow C_2H_5COO^-(aq) + H_2O(l)$

Acid-Base Titrations

- In a ***titration***, the concentration of one solution is used to determine the concentration of another.

- An ***acid-base indicator*** has different colors in acid and base, and is used to monitor the progress of a titration experiment.

- At the ***equivalence point***, the mol of H^+ from the acid equals the mol of OH^- ion produced by the base. *i.e.* pH of the solution = 7

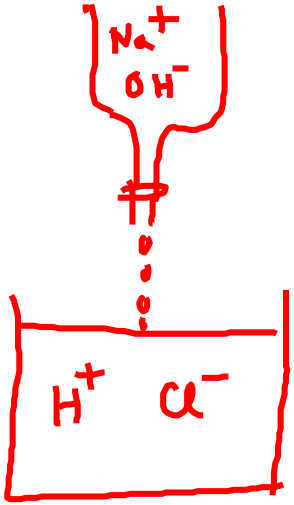
- The ***end point*** occurs when there is a slight excess of base and the **indicator changes color** permanently. *i.e.* pH is slightly greater than 7

Sample Problem 4.16

A 50.00 mL sample of HCl is titrated with 0.1524 *M* NaOH. The buret containing NaOH reads 0.55 mL at the beginning and 33.87 mL at the end point. Find the molarity of the HCl solution.

$$\frac{M_A \times V_A}{n_A} = \frac{M_B \times V_B}{n_B}$$

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



Ans: 0.102 M

CLASS ACTIVITY

Problem 4.37

Barium nitrate solution reacts with aqueous sodium carbonate to form a solid precipitate of barium carbonate and aqueous sodium nitrate. Write down **(a)** the balanced chemical equation, **(b)** total ionic equation, and **(c)** net ionic equation.

Problem 4.44 a)

Potassium carbonate solution reacts with aqueous barium hydroxide to form a solid precipitate of barium carbonate and aqueous potassium hydroxide. Write down **(a)** the balanced chemical equation, **(b)** total ionic equation, and **(c)** net ionic equation.

Problem 4.45 b)

Ammonium sulfate solution reacts with aqueous barium chloride to form a solid precipitate of barium sulfate and aqueous ammonium chloride. Write down **(a)** the balanced chemical equation, **(b)** total ionic equation, and **(c)** net ionic equation.

Reduction-Oxidation (Redox) Reaction

Reduction-Oxidation (Redox) Reactions

- **Oxidation** is the ***loss*** of electrons while **reduction** is the ***gain*** of electrons.

- Alternatively, **oxidation** refers to the ***increase*** in oxidation number while **reduction** refers to the ***decrease*** in oxidation number.

- Simple mnemonic: **OIL RIG**

✓ **OIL** → **O**xidation **I**s **L**oss

✓ **RIG** → **R**eduction **I**s **G**ain

- A ***reducing agent*** loses electrons and gets **oxidized**.

- An ***oxidizing agent*** gains electrons and gets **reduced**.

- A **redox reaction** involves ***electron transfer***. Oxidation and reduction occur together.

$$\overset{0}{2Mg(s)} + \overset{0}{O_2(g)} \rightarrow \overset{+2\ -2}{2MgO(s)}$$

Rules for Assigning an Oxidation Number (O.N.)

General rules

1. For an atom in its elemental form (Na, O_2, Cl_2, etc.): O.N. = 0
2. For a monoatomic ion: O.N. = ion charge
3. The sum of O.N. values for the atoms in a compound equals zero. The sum of O.N. values for the atoms in a polyatomic ion equals the ion's charge.

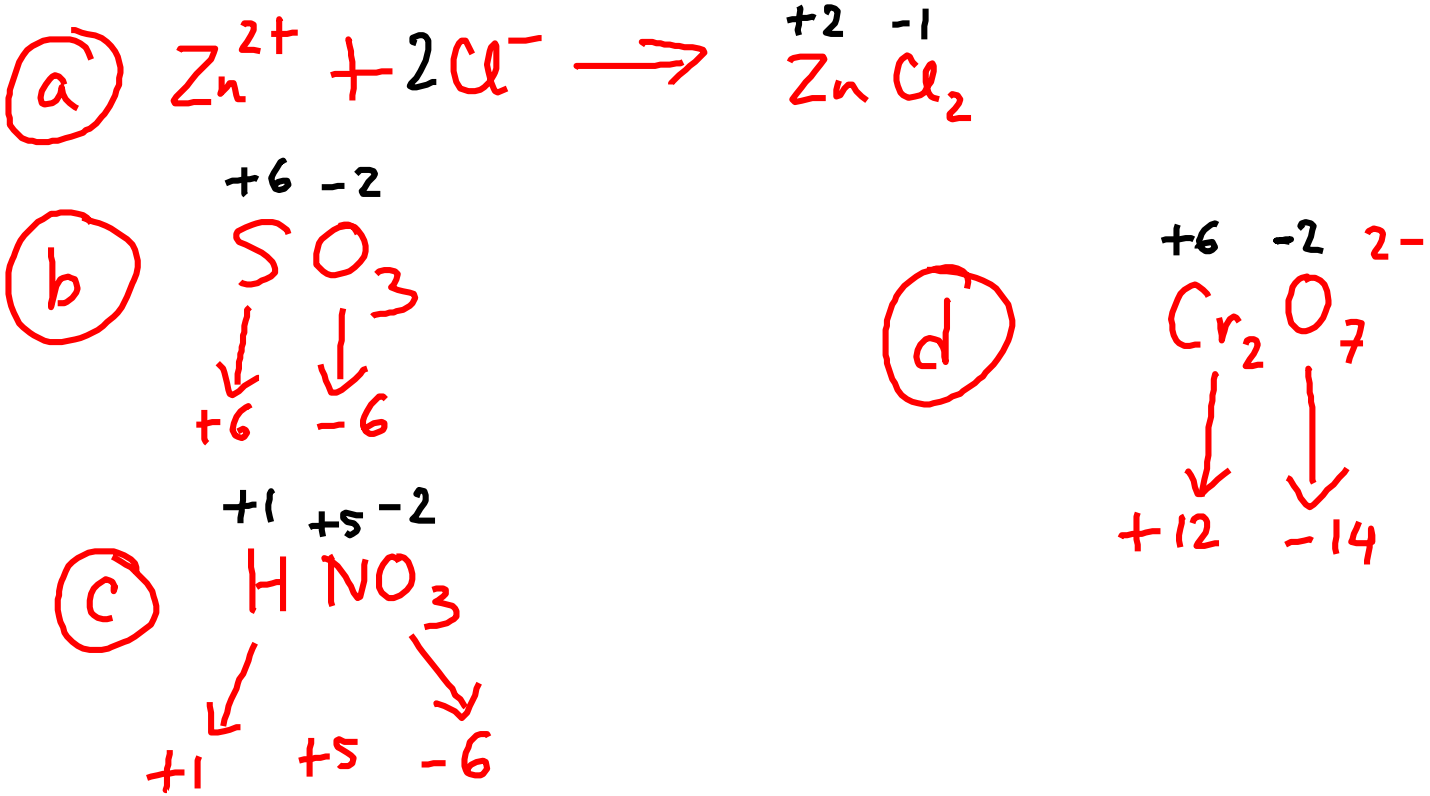
Rules for Specific Atoms or Periodic Table Groups

1.	For Group 1A(1):	O.N. = +1 in all compounds
2.	For Group 2A(2):	O.N. = +2 in all compounds
3.	For hydrogen:	O.N. = +1 in combination with nonmetals
		O.N. = -1 in combination with metals and boron
4.	For fluorine:	O.N. = -1 in all compounds
5.	For oxygen:	O.N. = -1 in peroxides
		O.N. = -2 in all other compounds(except with F)
6.	For Group 7A(17):	O.N. = -1 in combination with metals, nonmetals (except O), and other halogens lower in the group

Sample Problem 4.17

Determine the oxidation number of each element in these species:
(a) zinc chloride **(b)** sulfur trioxide **(c)** nitric acid **(d)** dichromate ion

SOLUTION



Sample Problem 4.18

Use oxidation numbers to decide whether the following is a redox reaction. If so, then identify the ***oxidizing agent*** and the ***reducing agent***.

a) $2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$

0 +1 +6 -2 +3 +6 -2 0

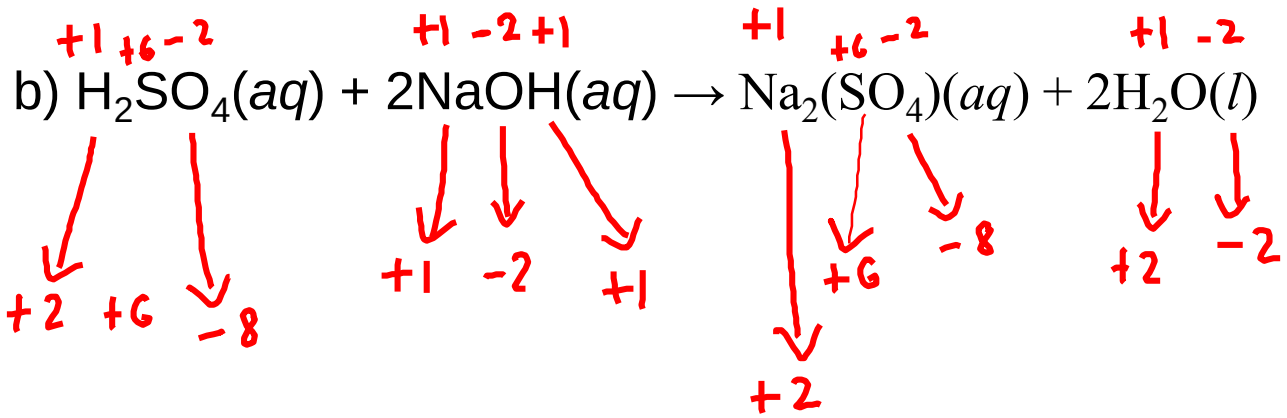
+2 +6 -8 +6 +18 -24

Reducing agent: Al is oxidized. $0 \longrightarrow +3$

Oxidizing agent: H is reduced. $+1 \longrightarrow 0$

Sample Problem 4.18

Use oxidation numbers to decide whether the following is a redox reaction. If so, then identify the ***oxidizing agent*** and the ***reducing agent***.



Reducing agent:

Oxidizing agent:

Not a redox reaction.

Sample Problem 4.18

Use oxidation numbers to decide whether the following is a redox reaction. If so, then identify the ***oxidizing agent*** and the ***reducing agent***.

+2 -2 +2 -2 0 +4 -2

c) $PbO(s) + CO(g) \rightarrow Pb(s) + CO_2(g)$

+4 -4

Reducing agent: C is oxidized. +2 → +4

Oxidizing agent: Pb is reduced. +2 → 0

Types of Redox Reactions

- **Combination Reaction**
  - Two or more reactants combine to form a new compound: **X + Y → Z**

- **Decomposition Reaction**
  - A single compound decomposes to form two or more products: **Z → X + Y**

- **Displacement Reaction**
  - *metathesis* or *double displacement*: **AB + CD → AD + CB**
  - single displacement: **X + YZ → XZ + Y**

- **Combustion Reaction**
  - the process of burning in O_2

Sample Problem 4.20

Classify the following redox reaction as a ***combination***, ***decomposition***, or ***displacement*** reaction. Write a balanced molecular equation, and identify the oxidizing and reducing agents.

hydrogen peroxide(*l*) → water(*l*) + oxygen gas

SOLUTION

$$2\,\overset{+1\ -1}{H_2O_2}\,(l) \longrightarrow 2\,\overset{+1\ -2}{H_2O}\,(l) + \overset{0}{O_2}\,(g)$$

+2 −2

Decomposition Reaction

O is simultaneously getting oxidized & reduced

−1 → 0 −1 → −2

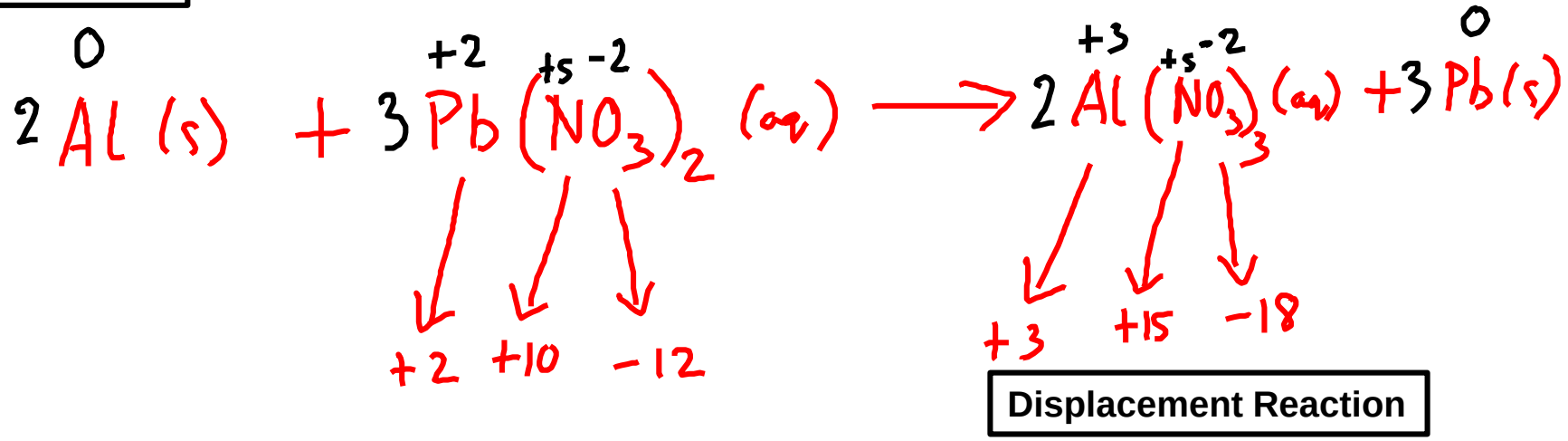
Disproportionation reaction

Sample Problem 4.20

Classify the following redox reaction as a ***combination***, ***decomposition***, or ***displacement*** reaction. Write a balanced molecular equation, and identify the oxidizing and reducing agents.

aluminum(*s*) + lead(II) nitrate(*aq*) → aluminum nitrate(*aq*) + lead(*s*)

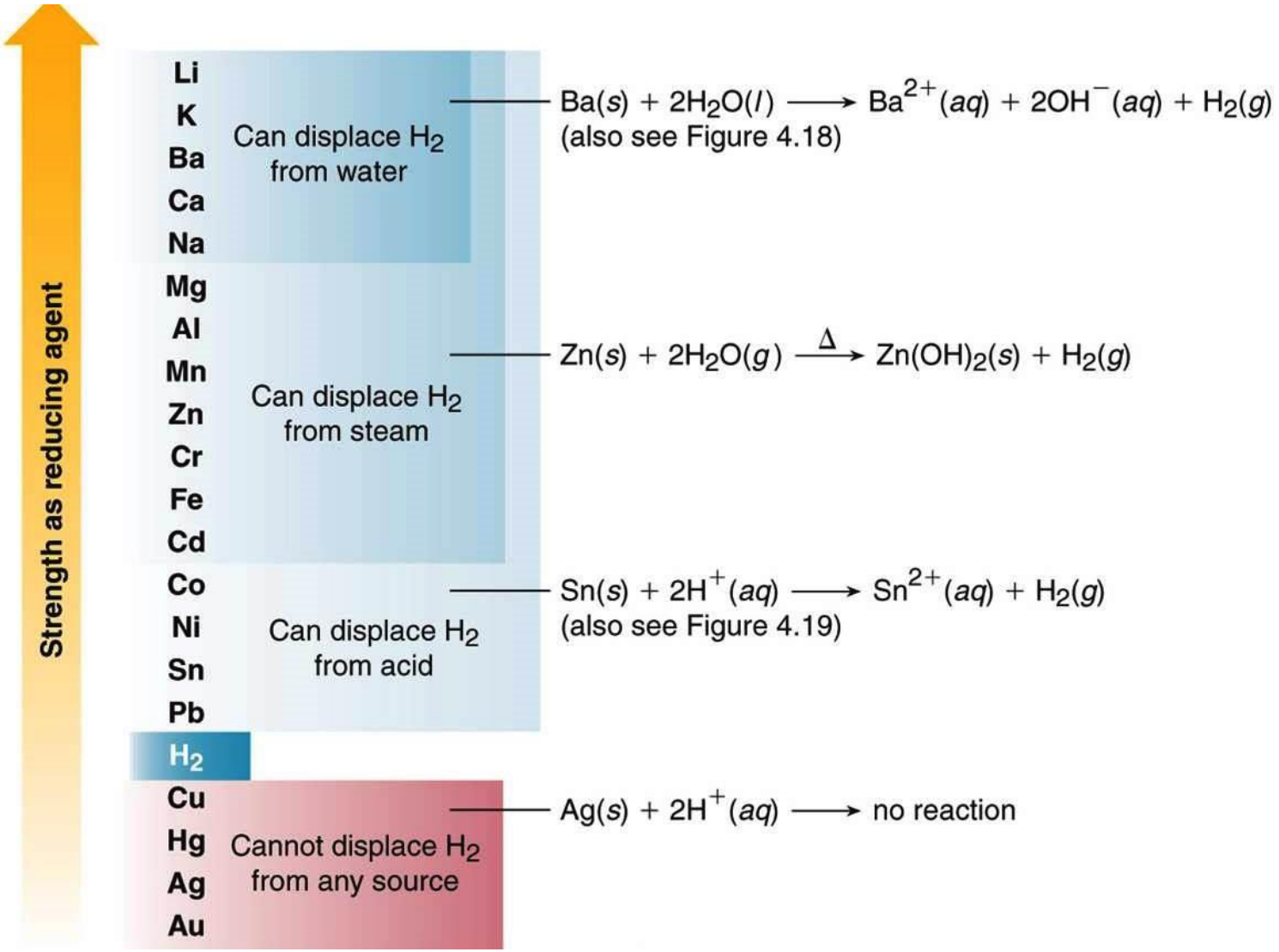
SOLUTION



Al is oxidized. 0 → +3

Pb is reduced. +2 → 0

Reactivity Series of Metals



A Trick to Remember the Reactivity Series

po-ca-so-m-al-z-i-l-hy-co-m-si

po → Potassium (K)
ca → Calcium (Ca)
so → Sodium (Na)
m → Magnesium (Mg)
al → Aluminum (Al)
z → Zinc (Zn)
i → Iron (Fe)
l → Lead (Pb)
hy → Hydrogen (H)
co → Copper (Cu)
m → Mercury (Hg)
si → Silver (Ag)

Examples of displacement reactions

$K(s) + Mg(NO_3)_2(aq) \rightarrow KNO_3(aq) + Mg(s)$

$Zn(s) + Mg(NO_3)_2(aq) \rightarrow$ No reaction

Thank you.

Any Questions?