Chapter 4 - Aqueous Reactions and Solution Stoichiometry

Section 2 – Precipitation and Neutralization

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Introduction - Types of Reactions

You have already learned previously about this type of classification of reactions: how **atoms are rearrangement**. Just to review there are four classifications which we will bring up again in this chapter.

- **Synthesis** (combination): two substances combine to form one.

  $2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$

- **Double Displacement**: A reaction in which two elements displaces two elements.

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

- **Single displacement**: A reaction where one element displaces one other element.

  $Zn_{(s)} + CuSO_{4\,(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$

- **Decomposition**: A reaction in which a single compound reacts to give two or more substances.

  $2HgO_{(s)} \rightarrow 2Hg_{(l)} + O_{2(g)}$

Types of Reactions – Chemical Type

Now we will focus on reactions in water/aqueous system. Dissociation occurs in ionic substances in water and the ions produced can react with each other as they are all in solution now. Below are the reactions we will cover.

Precipitation Reactions: In this a solid is formed when two solutions are mixed. This means that one substance combination in the solution is not soluble in water.

Neutralization Reactions: Reaction between an acid and base. This usually results in forming salt and water.

Oxidation–Reduction Reactions: One can recognize these reactions by seeing if oxygen or hydrogen is being added or removed. OR check if there is a transfer of electrons from one element/ion to another.

All these reactions have water as a solvent.

Precipitation Reactions

Precipitation (formation of a solid from two aqueous solutions) occurs when product is insoluble in water. The ions produced in water can react with each other and if their solubility is low in water they will precipitate.

It is good to remember that not everything dissolves in water, that is why this earth is not just a big globe of water, and you don't dissolve in water when you jump in the swimming pool.

- Precipitation reaction type: Double displacement.
- What is solubility? Solubility is defined as the maximum amount of a solid that can dissolve in a given amount of solvent at a specific temperature.
- Prediction of precipitate is based on solubility rules.

Solubility Guidelines

Soluble		Insoluble
Group I salts		
Ammonium salts		
Nitrates		No exceptions
Acetates		
Perchlorates		
Halides	except	Pb^{2+}, Ag^{+}, Hg_2^{2+}
Sulfates	except	Sr^{2+}, Ba^{2+}, Ca^{2+}, Pb^{2+}, Hg_2^{2+}, Ag^{+}
Except Groups II salts		Carbonates
		Phosphates
Ca^{2+}, Ba^{2+}		Hydroxides
Except Groups II salts		Sulfides

Solved Problem: Predicting precipitation

For the compounds and reaction given below, predict if there will be precipitation.

a) Classify the following as soluble or insoluble in water: $Ba(NO_3)_2$, AgI, $Mg(OH)_2$.

b) Predict the precipitate in the following equation.

$$Pb(NO_3)_{2(aq)} + 2NaI_{(aq)} \rightarrow 2NaNO_3 + PbI_2$$

a) $Ba(NO_3)_2$ *soluble*

AgI *insoluble*

$Mg(OH)_2$ *insoluble*

b) $Pb(NO_3)_{2(aq)} + 2NaI_{(aq)} \rightarrow 2NaNO_3 + PbI_2$

PbI_2 should precipitate according to solubility rules

Writing Equations in Aqueous Solutions

A chemical equation in which the reactants and products are written as if they were molecular substances, even though they may exist in solution as ions.

Symbols indicating the states are include: (*s*), (*l*), (*g*), (*aq*). Write them as subscripts.

Molecular Equation:

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

Although $AgNO_3$, NaCl, and $NaNO_3$ exist as ions in aqueous solutions, they are written as compounds in the molecular equation.

Ionic Equation:

$$Ag^+_{(aq)} + NO_3^-{}_{(aq)} + Na^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)} + Na^+_{(aq)} + NO_3^-{}_{(aq)}$$

All compounds that dissociate are shown as ions.

Net Ionic Equation:

In this the **spectator ions** (ions on both sides of the equation) are eliminated.

$$Ag^+_{(aq)} + \mathbf{NO_3^-}_{(aq)} + \mathbf{Na^+}_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)} + \mathbf{Na^+}_{(aq)} + \mathbf{NO_3^-}_{(aq)}$$

Net ionic equation represents the ions reacting. Those will be (g), (l) and (s) products formed.

$$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$$

Solved Problem: Writing precipitation equation

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$NaOH_{(aq)} + MgCl_{2\,(aq)} \rightarrow$

Step 1: Determine the product formulas by double displacement method.

- Na^+ and Cl^- make NaCl
- Mg^{2+} and OH^- make $Mg(OH)_2$

Step 2: Determine whether the products are soluble.

- NaCl is soluble and $Mg(OH)_2$ is insoluble.

Molecular Equation

Balance the reaction and include state symbols.

$2NaOH_{(aq)} + MgCl_{2(aq)} \rightarrow 2NaCl_{(aq)} + Mg(OH)_{2(s)}$

Ionic Equation

$2Na^+_{(aq)} + 2OH^-_{(aq)} + Mg^{2+}_{(aq)} + 2Cl^-_{(aq)} \rightarrow 2Na^+_{(aq)} + 2Cl^-_{(aq)} + Mg(OH)_{2(s)}$

Net Ionic Equation

$$2OH^-_{(aq)} + Mg^{2+}_{(aq)} \rightarrow Mg(OH)_{2(s)}$$

Solved Problem: Writing precipitation equation

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$K_3PO_{4\,(aq)} + CaCl_{2\,(aq)} \rightarrow$

Determine the product formulas:

K^+ and Cl^- make KCl; Ca^{2+} and PO_4^{3-} make $Ca_3(PO_4)_2$

Determine whether the products are soluble:

KCl is soluble and $Ca_3(PO_4)_2$ is insoluble

Molecular Equation

(Balance the reaction and include state symbols)

$2K_3PO_{4(aq)} + 3CaCl_{2(aq)} \rightarrow 6KCl_{(aq)} + Ca_3(PO_4)_{2\,(s)}$

Ionic Equation

$6K^+_{(aq)} + 2PO_4^{3-}{}_{(aq)} + 3Ca^{2+}_{(aq)} + 6Cl^-_{(aq)} \rightarrow 6K^+_{(aq)} + 6Cl^-_{(aq)} + Ca_3(PO_4)_{2\,(s)}$

Net Ionic Equation

$2PO_4^{3-}{}_{(aq)} + 3Ca^{2+}_{(aq)} \rightarrow Ca_3(PO_4)_{2\,(s)}$

Solved Problem: Writing precipitation equation

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$KBr_{(aq)} + MgSO_{4\,(aq)} \rightarrow$

Determine the product formulas by double displacement method

- K^+ and SO_4^{2-} make K_2SO_4
- Mg^{2+} and Br^- make $MgBr_2$

$KBr_{(aq)} + MgSO_{4\,(aq)} \rightarrow K_2SO_{4\,(aq)} + MgBr_{2\,(aq)}$

Determine whether the products are soluble:

K_2SO_4 is soluble and $MgBr_2$ is soluble

$KBr_{(aq)} + MgSO_{4(aq)} \rightarrow$ no reaction

Solved Problem: Writing precipitation equation

Aqueous solutions of silver nitrate and sodium sulfate are mixed. Write the net ionic reaction.

$$2AgNO_{3(aq)} + Na_2SO_{4(aq)} \rightarrow 2NaNO_{3(?)} + Ag_2SO_{4(?)}$$

Determine solubility of salts. All nitrates are soluble but silver sulfate is insoluble.

Molecular Equation

$$2AgNO_{3(aq)} + Na_2SO_{4(aq)} \rightarrow 2NaNO_{3(aq)} + Ag_2SO_{4\,(s)}$$

Ionic equation

$$2Ag^+_{(aq)} + 2NO_3^-{}_{(aq)} + 2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow 2Na^+_{(aq)} + 2NO_3^-{}_{(aq)} + Ag_2SO_{4\,(s)}$$

Cancel spectators

$$2Ag^+_{(aq)} + \cancel{2NO_3^-{}_{(aq)}} + \cancel{2Na^+_{(aq)}} + SO_4^{2-}{}_{(aq)} \rightarrow \cancel{2Na^+_{(aq)}} + \cancel{2NO_3^-{}_{(aq)}} + Ag_2SO_{4\,(s)}$$

Net ionic equation

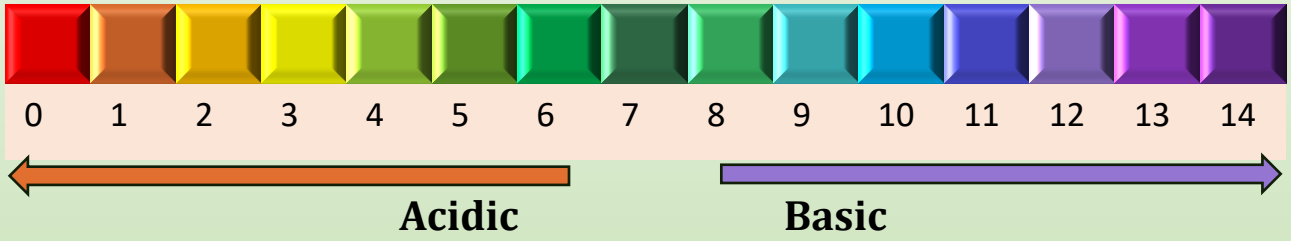
$$2Ag^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow Ag_2SO_{4\,(s)}$$

Neutralization Reactions (Acid-Base)

Acids	Bases
Arrhenius Acid A substance that produces hydrogen ions, H^+, when dissolved in water.	**Arrhenius Base** A substance that produces hydroxide ions, OH^-, when dissolved in water.
Brønsted–Lowry Acid A molecule or ion that donates a proton, H^+, to another in a reaction.	**Brønsted–Lowry Base** A molecule or ion that accepts a proton, H^+, from another in a reaction.
Sour	Bitter
Corrosive	Caustic, slippery
pH value 1-7	pH value 7-14
Strong acids (inorganic acids) – ionize completely in water, e.g.: HNO_3, H_2SO_4, $HClO_4$, HCl, HBr, HI	Strong bases (inorganic bases) – ionize completely in water; most are hydroxides, e.g.: NaOH, KOH, $Ca(OH)_2$
Weak acids – ionize partially in water, e.g. HF Organic acid: $HC_2H_3O_2$ (CH_3COOH)	Weak bases– ionize partially in water, e.g.: NH_4OH, Na_2CO_3, $NaHCO_3$ Organic bases: CH_3NH_2

More on Acids-Bases

Indicators: These are chemicals that help to determine if a chemical is an acid or base by showing different colors in different solutions. Below are the colors for universal indicator.



Monoprotic Acid: An acid that gives one proton (H^+) during dissociation, e.g., HCl has only one proton to give

Polyprotic Acid: An acid that results in two or more acidic hydrogens per molecule, e.g., H_2SO_4, sulfuric acid can give 2 protons.

Strong Acids

The acids given below are strong acids and will dissociate completely.

Hydrochloric acid	$HCl_{(aq)}$	$H^+_{(aq)} + Cl^-_{(aq)}$
Hydrobromic acid	$HBr_{(aq)}$	$H^+_{(aq)} + Br^-_{(aq)}$
Nitric acid	$HNO_{3(aq)}$	$H^+_{(aq)} + NO_3^-{}_{(aq)}$
Chloric acid	$HClO_{3(aq)}$	$H^+_{(aq)} + ClO_3^-{}_{(aq)}$
Sulfuric acid	$H_2SO_{4(aq)}$	$2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

Acid-Base Neutralization Reactions

Neutralization Reaction:

- Almost all acid base reactions are double displacement reactions.
- Most will produce a salt and water as product.
- Carbonates and sulfites give CO_2 and SO_2 gases in product.

Neutralization: Reaction between an acid and a base

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

Molecular equation:

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Ionic equation:

$$H^+_{(aq)} + \cancel{Cl^-_{(aq)}} + \cancel{Na^+_{(aq)}} + OH^-_{(aq)} \rightarrow \cancel{Na^+_{(aq)}} + \cancel{Cl^-_{(aq)}} + H_2O_{(l)}$$

Net ionic equation:

$$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$$

Solved Problem: Writing neutralization equation

Write the molecular, ionic, and net ionic equations for the neutralization of sulfuric acid, H_2SO_4, by potassium hydroxide, KOH.

The reaction is a double displacement reaction.

Molecular Equation

(Balance the reaction and include state symbols)

$$H_2SO_{4(aq)} + 2KOH_{(aq)} \rightarrow 2H_2O_{(l)} + K_2SO_{4(aq)}$$

Ionic Equation

$$2H^+_{(aq)} + SO_4^{2-}{}_{(aq)} + 2K^+_{(aq)} + 2OH^-_{(aq)} \rightarrow 2H_2O_{(l)} + 2K^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

Net Ionic Equation

$$2H^+_{(aq)} + 2OH^-_{(aq)} \rightarrow 2H_2O_{(l)}$$

Neutralization Reactions Producing Gases

Sulfides, carbonates, sulfites react with acid to form a gas.

$Na_2S_{(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2S(g)$

$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2O(l) + CO_2(g)$

You can write it as a double displacement reaction.

Baking soda (sodium hydrogen carbonate) reacting with acetic acid in vinegar to give bubbles of carbon dioxide.

$NaHCO_{3(aq)} + CH_3COOH_{(aq)} \rightarrow NaCH_3COO_{(aq)} + H_2CO_3$

$H_2CO_3 \rightarrow H_2O(l) + CO_2(g)$

Solved Problem: Writing neutralization equation with gases

Write the molecular, ionic, and net ionic equations for the neutralization of sodium sulfite with hydrochloric acid.

Molecular Equation

(Balance the reaction and include state symbols)

$$Na_2SO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(l)} + SO_{2(g)}$$

Ionic Equation

$$2Na^+_{(aq)} + SO_3^{2-}{}_{(aq)} + 2H^+_{(aq)} + 2Cl^-_{(aq)} \rightarrow 2Na^+_{(aq)} + 2Cl^-_{(aq)} + H_2O_{(l)} + SO_{2(g)}$$

Net Ionic Equation

$$SO_3^{2-}{}_{(aq)} + 2H^+_{(aq)} \rightarrow H_2O_{(l)} + SO_{2(g)}$$

Key Words and Concepts

- Precipitation Reactions
- Solubility Rules
- Acid–Base Reactions