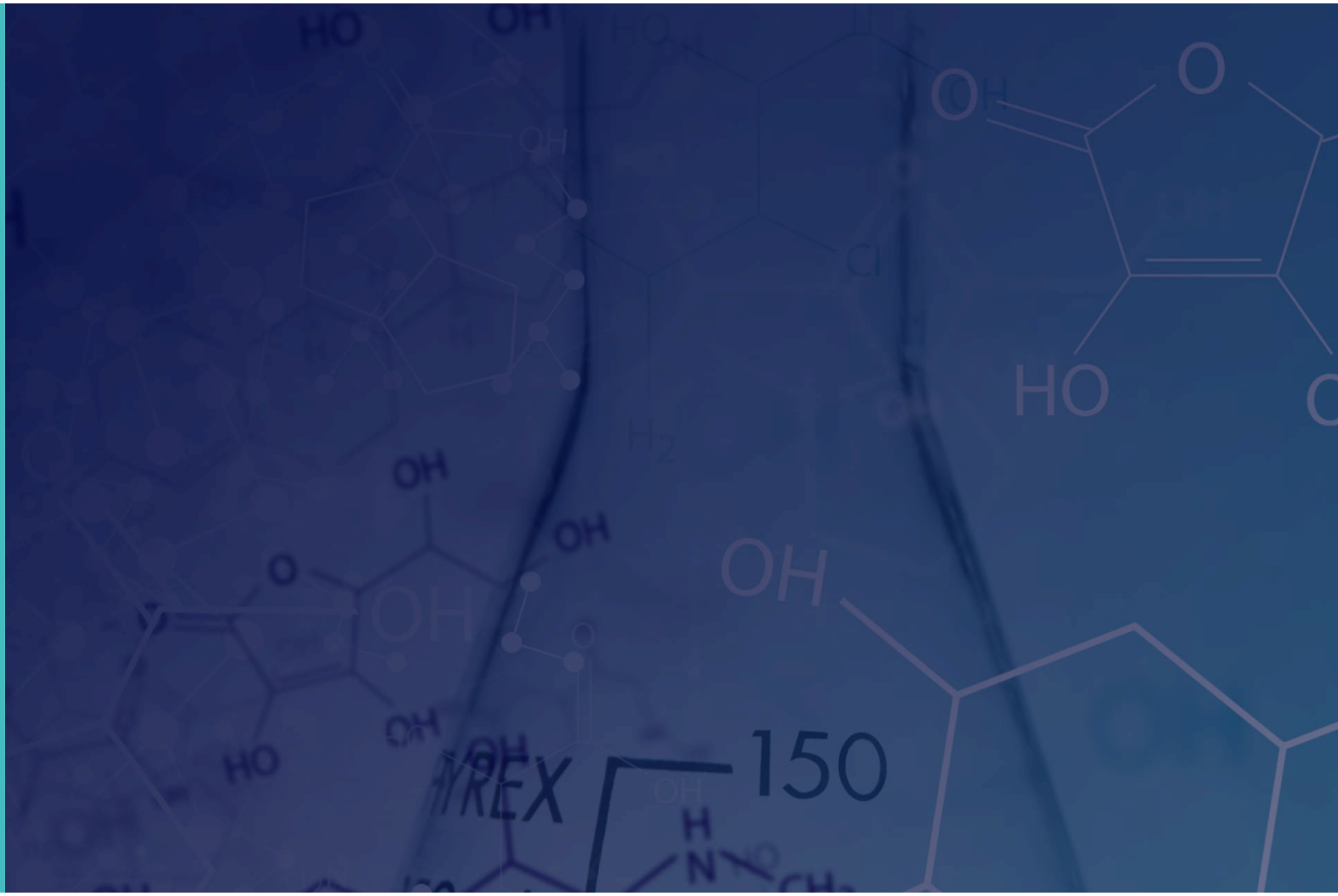

Ontario High School

Grade 11 Chemistry

Summer 2024, Chapter 4 Notes

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4. Chemical Reactions

4.1 Expressing Chemical Reactions

4.1.1

Balancing Chemical Reaction Equations

- A balanced chemical equation tells us the correct proportions of chemicals in a chemical reaction.

Steps to Balance Chemical Equations

Example: Nitrogen gas reacting with hydrogen gas to give us ammonia

$$N_2\,(g) + H_2(g) \rightarrow NH_3(g)$$

1. Count the number of entities (atoms / ions / polyatomic ions) of each type on either side of the arrow. Look at subscripts to see exactly how much of an entity we have on each side.

2. Multiply the chemical formulas by an appropriate coefficient until all entities are balanced.

3. Check whether the numbers of each entity on both sides are balanced.

4.1.2

Ways to Write Out Chemical Reactions

Formula Equation

- This is the way we are most familiar with

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2H_2O(\ell) + Na_2SO_4(aq)$$

Total Ionic Equation

- To write the complete ionic equation, we need to look at the formula equation and identify which of the product and reactants can dissociate or ionize. Then write out the equation with all of the ions.

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2H_2O(\ell) + Na_2SO_4(aq)$$

Compounds in the formula equation	Can this compound dissociate/ionize?	The dissociation/ionization reaction

- Next, since we figured out all the molecules that dissociate or ionize and balanced the equations, we need to put everything back into the formula equation:

Net Ionic Equation:

- For this equation, we take the total ionic equation and cross anything out that appears in equal quantities on both sides so that we are left with the net ionic equation.

$$2H^+ + SO_4^{2-}(aq) + 2Na^+ + 2OH^-(aq) \rightarrow 2H_2O(\ell) + 2Na^+ + SO_4^{2-}(aq)$$

- **Spectator ions** are the ions that are not involved in the chemical reaction. These are the ions that appear as both reactants and products and remain unchanged. In this case, the spectator ions are _____ and _____.

4.1.3

Example: Balancing Chemical Equations with Polyatomic Ions

Balance the following chemical equation:

$$Na_3PO_4(aq) + Ba(NO_3)_2(aq) \rightarrow NaNO_3(aq) + Ba_3(PO_4)_2(aq)$$

4.1.4

Practice: Identifying Balanced Chemical Reactions

Which of the following are balanced chemical equations? Select all that apply.

- $P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$ ☐
- $A\ell(s) + C\ell_2(g) \rightarrow A\ell_2C\ell_6(s)$ ☐
- $Fe_3O_4(s) + 2C(s) \rightarrow Fe(s) + 2CO_2(g)$ ☐
- $Ca(OH)_2(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + 2H_2O(\ell)$ ☐

4.1.5

MARK YOURSELF QUESTION

1. Grab a piece of paper and try this problem yourself.
2. When you're done, check the "I have answered this question" box below.
3. View the solution and report whether you got it right or wrong.

Practice: Balanced Equations

When given the unbalanced chemical equation: $Na + C\ell_2 \rightarrow NaC\ell$

Student A balanced it as follows: $Na + C\ell_2 \rightarrow NaC\ell_2$

Student B balanced it as follows: $2Na + C\ell_2 \rightarrow 2NaC\ell$

Both are balanced, but which is correct and why?

Practice: Balancing Chemical Equations

Balance the following chemical equations. If the coefficient is 1, please include it as well.

a. ( ) $Mg(OH)_2$ + ( ) $HBr \rightarrow$ ( ) $MgBr_2$ + ( ) H_2O

b. ( ) Fe_2O_3 + ( ) $H_2 \rightarrow$ ( ) Fe + ( ) H_2O

c. ( ) P + ( ) $Cl_2 \rightarrow$ ( ) PCl_3

d. ( ) $NaHCO_3 \rightarrow$ ( ) Na_2CO_3 + ( ) CO_2 + ( ) H_2O

4.2 Chemical Reactions

4.2.1

Formation and Decomposition Reactions

- A **formation or synthesis reaction** is a reaction in which two or more reactants come together to form one larger compound. The general formula for a synthesis reaction is:

$$\boxed{\mathrm{A} + \mathrm{B} \rightarrow \mathrm{AB}}$$

Example 1: Two elements combining to form a compound

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

Example 2: An element reacting with a compound to form a new. larger compound

$$2NaC\ell(aq) + 3O_2(g) \rightarrow 2NaC\ell O_3(aq)$$

Example 3: Two compounds combining to form an even more complex compound

$$CaO(s) + H_2O(\ell) \rightarrow Ca(OH)_2(aq)$$

- A **decomposition reaction** is one in which a complex compound breaks down into simpler compounds. The general formula for a decomposition reaction is:

$$\boxed{\mathrm{AB} \rightarrow \mathrm{A}+\mathrm{B}}$$

Example 1: Binary compounds decomposing into their elements

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

Example 2: A compound decomposing into a simpler compound and an element

$$2KC\ell O_3(s) \rightarrow 2KC\ell(s) + 3O_2(g)$$

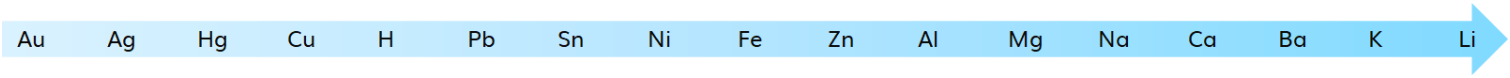
Example 3: A compound decomposing into simpler compounds

$$NH_4C\ell(s) \rightarrow NH_3(g) + HCl(aq)$$

4.2.2

Replacement Reactions

- In order for a displacement reaction to occur, we need to look at the activity series of metals
- A more reactive element will displace a less reactive element in a displacement reaction



- In **single replacement reactions**, an element replaces a similar element in another reactant. The general formula for a single replacement reaction is:

$$\boxed{\mathrm{AB} + \mathrm{C} \rightarrow \mathrm{AC} + \mathrm{B}}$$

Example 1: Hydrogen can be replaced by more reactive metals

$$2Na(s) + 2H_2O(\ell) \rightarrow H_2(g) + 2NaOH(aq)$$

Example 2: Metals can replace other metals

$$Mg(s) + Cu(NO_3)_2(aq) \rightarrow Mg(NO_3)_2(aq) + Cu(s)$$

Example 3: Halogens will replace other halogens. Activity increases from the bottom to the top in the group.

$$2NaBr(aq) + C\ell_2(g) \rightarrow 2NaC\ell(aq) + Br_2(\ell)$$

- In **double replacement reactions**, the positive or negative ions of two ionic compounds switch places to form new compounds. The general formula for a double replacement reaction is:

$$\boxed{\mathrm{AB} + \mathrm{CD} \rightarrow \mathrm{AD} + \mathrm{CB}}$$

Example 1: A double replacement reaction can be used to precipitate a compound

$$2HC\ell(aq) + Pb(NO_3)_2(sq) \rightarrow 2HNO_3(aq) + PbC\ell_2(s)$$

Example 2: A double replacement reaction can be used to release a gas

$$FeS(s) + 2HC\ell(aq) \rightarrow H_2S(g) + FeC\ell_2(aq)$$

Example 3: Neutralization reactions between an acid and a base are double replacement reactions

$$NaOH(aq) + HC\ell(aq) \rightarrow H_2O(\ell) + NaC\ell(aq)$$

4.2.3 **Example: Using the Activity Series**

Example: Using the Activity Series

Using the activity series, predict the products for each reaction. If there is no reaction, write NR (no reaction). If a reaction occurs, complete the equation and balance it.

a. $HC\ell(aq) + Mg(s) \rightarrow$

b. $BaC\ell_2(aq) + Pb(s) \rightarrow$

c. $NaC\ell(aq) + F_2(g) \rightarrow$

d. $PbC\ell_2(aq) + Br_2(\ell) \rightarrow$

b.

c.

d.

4.2.4

Classify the following reactions as synthesis (S), decomposition (D), single-replacement (SR) or double-replacement (DR)

1. $Al_2(SO_4)_3 + 3BaCl_2 \rightarrow 3BaSO_4 + 2A\ell C\ell_3$
2. $Al_2S_3 \rightarrow 2Al + 3S$
3. $2NaOH + CuSO_4 \rightarrow Na_2SO_4 + Cu(OH)_2$
4. $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$

1. S or D or SR or DR

---

2. S or D or SR or DR

---

3. S or D or SR or DR

---

4. S or D or SR or DR

4.2.5

When a solution sodium bicarbonate is heated, water vapour, carbon dioxide gas and a precipitate are formed. What type of reaction is this?

- synthesis
- single replacement
- decomposition
- double replacement

4.2.6

Practice: Using the Activity Series

Based on the activity series of metals, which of the following reactions will not occur? Select all that apply.

- $Au(s) + H_2SO_4(aq) \rightarrow$ ☐
- $Fe(s) + H_2SO_4(aq) \rightarrow$ ☐
- $Hg(s) + H_2SO_4(aq) \rightarrow$ ☐
- $A\ell(s) + H_2SO_4(aq) \rightarrow$ ☐

4.3 Chemical Analysis

4.3.1

Precipitation Reactions

- Two soluble ionic compounds react to form an insoluble product, that is a precipitate (solid)

$$MgC\ell_2(aq) + Ca(OH)_2(aq) \rightarrow Mg(OH)_2(s) + CaC\ell_2(aq)$$

- In this reaction, two water soluble salts (magnesium chloride and calcium hydroxide) react to form another soluble salt (calcium chloride) and a precipitate (magnesium hydroxide).
- How do we know magnesium hydroxide is insoluble? Check out the solubility chart below to predict the solubility of ionic compounds.

Solubility Rules

CATIONS	ALL group 1 alkali metals and ammonium (NH_4^+) compounds are soluble
HALIDES (Cl^-, I^- Br^-)	MOST halides are soluble EXCEPT halides of silver (Ag^+), mercury (Hg^{2+}) and lead (Pb^{2+})
SOLUBLE ANIONS	ALL nitrates (NO_3^-) and acetates (CH_3COO^-) are soluble
SULFATES (SO_4^{2-})	MOST sulfates are soluble EXCEPT those of barium (Ba^{2+}), strontium (Sr^{2+}), calcium (Ca^{2+}) and lead (Pb^{2+})
INSOLUBLE ANIONS	MOST phosphates (PO_4^{3-}), carbonates (CO_3^{2-}) and sulfides (S^{2-}) are insoluble EXCEPT group 1 alkali metals and ammonium (NH_4^+) compounds
HYDROXIDES (OH^-)	MOST hydroxides are insoluble EXCEPT group 1 alkali metals, calcium (Ca^{2+}), barium (Ba^{2+}), strontium (Sr^{2+}) and ammonium (NH_4^+) compounds

4.3.2

Hydrocarbon Combustion Reactions

- A **combustion reactions** is a reaction between a hydrocarbon (C_xH_y) with oxygen to produce carbon dioxide (CO_2) and water (H_2O).

$$C_xH_y\,(g)\ +\ O_2\ (g)\ \ \rightarrow\ \ CO_2\ (g)\ +\ H_2O\ (g)$$

- Combustion reactions are commonly used in elemental analysis to determine the empirical formula of a compound.

Complete vs Incomplete Combustion:

- **Complete combustion** occurs when **an excess of oxygen** reacts with a hydrocarbon **to produce carbon dioxide and water.**

$$\boxed{\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}}$$

- **Incomplete combustion** occurs when there is **insufficient oxygen** present and the oxygen reacts with the hydrocarbon to form water and either carbon monoxide or carbon, or both

$$\boxed{\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon monoxide} + \text{carbon} + \text{water}}$$

Steps to Balance a combustion reaction:

1. Balance the carbons
2. Balance the hydrogens
3. Balance the oxygens using ONLY the coefficient of elemental oxygen (O_2)
4. If the equation has any fractions (often times the coefficient in front of O_2 is a fraction), multiply the ENTIRE equation by 2

Example: Balance the following reaction

$$C_2H_6\,(g) \quad + \quad O_2\ (g) \quad \rightarrow \quad CO_2\ (g) \quad + \quad H_2O\ (g)$$

Example: Determining the Solubility of Salts

Decide whether these following ionic salts are soluble or not in water.

1) NaCl

2) AgCl

3) $BaSO_4$

4) KNO_3

4.3.4

Which of the following compounds is soluble in water at 25 °C?

- $Fe(OH)_2$
- HgS
- $(NH_4)_2SO_4$
- $CaCO_3$

4.3.5

Practice: Solubility Rules and Precipitation

Which of the following correctly describes what happens when aqueous solutions of ammonium carbonate, $(NH_4)_2CO_3$, and potassium bromide, KBr, are mixed?

- No precipitate forms
- A precipitate of $NH_4Br(s)$ forms
- A precipitate of $K_2CO_3(s)$ forms

4.3.6

Select the correct balanced equation for the complete combustion reaction expected to occur between C_4H_{10} and O_2.

- $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$
- $2C_4H_{10} + 7CO_2 \rightarrow 2CO_2 + 10H_2O + 13C$
- $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$
- $2C_4H_{10} + O_2 \rightarrow 8C + 10H_2 + O_2$