CHAPTER 8: CHEMICAL EQUATIONS

Enhanced Introductory College Chemistry

by Gregory Anderson; Caryn Fahey; Jackie MacDonald; Adrienne Richards; Samantha Sullivan Sauer; J.R. van Haarlem; and David Wegman;

Chapter Contents

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Please visit the web version of Enhanced Introductory College Chemistry (https://ecampusontario.pressbooks.pub/enhancedchemistry/) to access the complete book, interactive activities and ancillary resources.

In this chapter, you will learn about

- Components of a chemical equation
- Writing chemical compounds in a chemical reaction
- Balancing chemical reactions

- The 5 types of chemical reactions (combustion, combination, decomposition, single displacement and double displacement)

To better support your learning, you should be familiar with the following concepts before starting this chapter:

- States of matter
- Elements
- Compounds
- Moles
- Molar mass

Figure 8a: Many modern rocket fuels are solid mixtures of substances combined in carefully measured amounts and ignited to yield a thrust-generating chemical reaction. (credit: work courtesy of NASA/JPL-Caltech, JPL Image Policy.)

Solid-fuel rockets are a central feature in the world's space exploration programs, including the new Space Launch System being developed by the National Aeronautics and Space Administration (NASA) to replace the retired Space Shuttle fleet (Figure 8a). The engines of these rockets rely on carefully prepared solid mixtures of chemicals combined in precisely measured amounts. Igniting the mixture initiates a vigorous chemical reaction that rapidly generates large amounts of gaseous products. These gases are ejected from the rocket engine through its nozzle, providing the thrust needed to propel heavy payloads into space. Both the nature of this chemical reaction and the relationships between the amounts of the substances being consumed and produced by the reaction are critically important considerations that determine the success of the technology. This chapter will describe how to symbolize chemical reactions using chemical equations, how to classify some common chemical reactions by identifying patterns of reactivity, and how to determine the quantitative relations between the amounts of substances involved in chemical reactions – that is, the reaction *stoichiometry*.

Attribution & References

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8.1 WRITING AND BALANCING CHEMICAL EQUATIONS

Learning Objectives

By the end of this section, you will be able to:

- Derive chemical equations from narrative descriptions of chemical reactions
- Write and balance chemical equations in molecular formats

The preceding chapter introduced the use of element symbols to represent individual atoms. When atoms gain or lose electrons to yield ions, or combine with other atoms to form molecules, their symbols are modified or combined to generate chemical formulas that appropriately represent these species. Extending this symbolism to represent both the identities and the relative quantities of substances undergoing a chemical (or physical) change involves writing and balancing a **chemical equation**. Consider as an example the reaction between one methane molecule (CH_4) and two diatomic oxygen molecules (O_2) to produce one carbon dioxide molecule (CO_2) and two water molecules (H_2O). The chemical equation representing this process is provided in the upper half of Figure 8.1a, with space-filling molecular models shown in the lower half of the figure.

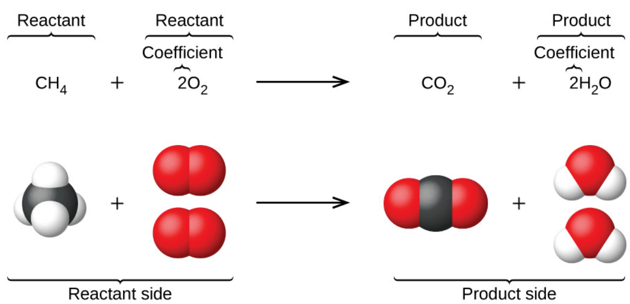

Figure 8.1a: The reaction between methane and oxygen to yield carbon dioxide and water (shown at bottom) may be represented by a chemical equation using formulas (top) (credit: *Chemistry (OpenStax)*, CC BY 4.0).

This example illustrates the fundamental aspects of any chemical equation:

1. The substances undergoing reaction are called **reactants**, and their formulas are placed on the left side of the equation.
2. The substances generated by the reaction are called products, and their formulas are placed on the right sight of the equation.
3. Plus signs (+) separate individual reactant and product formulas, and an arrow (⟶) separates the reactant and **product** (left and right) sides of the equation.
4. The relative numbers of reactant and product species are represented by **coefficients** (numbers placed immediately to the left of each formula). A coefficient of 1 is typically omitted.

It is common practice to use the smallest possible whole-number coefficients in a chemical equation, as is done in this example. Realize, however, that these coefficients represent the *relative* numbers of reactants and products, and, therefore, they may be correctly interpreted as ratios. Methane and oxygen react to yield carbon dioxide and water in a 1:2:1:2 ratio. This ratio is satisfied if the numbers of these molecules are, respectively, 1-2-1-2, or 2-4-2-4, or 3-6-3-6, and so on (Figure 8.1b). Likewise, these coefficients may be interpreted with regard to any amount (number) unit, and so this equation may be correctly read in many ways, including:

- *One* methane molecule and *two* oxygen molecules react to yield *one* carbon dioxide molecule and *two* water molecules.
- *One dozen* methane molecules and *two dozen* oxygen molecules react to yield *one dozen* carbon dioxide molecules and *two dozen* water molecules.
- *One mole* of methane molecules and *2 moles* of oxygen molecules react to yield *1 mole* of carbon dioxide molecules and *2 moles* of water molecules.

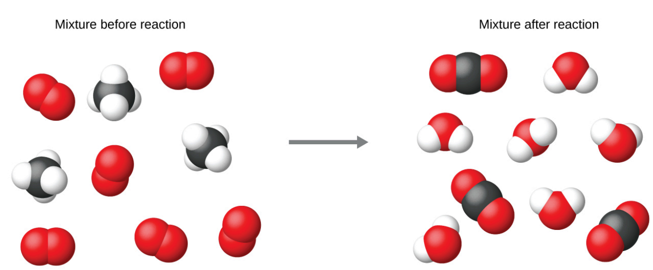

Figure 8.1b: Regardless of the absolute numbers of molecules involved, the ratios between numbers of molecules of each species that react (the reactants) and molecules of each species that form (the products) are the same and are given by the chemical reaction equation (credit: *Chemistry (OpenStax)*, CC BY 4.0).

Balancing Equations

The chemical equations described above are **balanced**, meaning that equal numbers of atoms for each element involved in the reaction are represented on the **reactant** and product sides. This is a requirement the equation must satisfy to be consistent with the law of conservation of matter. It may be confirmed by simply summing the numbers of atoms on either side of the arrow and comparing these sums to ensure they are equal. Note that the number of atoms for a given element is calculated by multiplying the coefficient of any formula containing that element by the element's subscript in the formula. If an element appears in more than one formula on a given side of the equation, the number of atoms represented in each must be computed and then added together. For example, both product species in the example reaction, CO_2 and H_2O, contain the element oxygen, and so the number of oxygen atoms on the product side of the equation is

$$(1\ \text{CO}_2\ \text{molecule} \times \frac{2\ \text{O atoms}}{\text{CO}_2\ \text{molecule}}) + (2\ \text{H}_2\text{O molecule} \times \frac{1\ \text{O atom}}{\text{H}_2\text{O molecule}}) = 4\ \text{O atoms}$$

The equation for the reaction between methane and oxygen to yield carbon dioxide and water is confirmed to be balanced per this approach, as shown here:

$$\text{CH}_4 + 2\ \text{O}_2 \longrightarrow \text{CO}_2 + 2\ \text{H}_2\text{O}$$

Tally Chart for Reaction of Methane and Oxygen to Yield Carbon Dioxide and Water

Element	Reactants	Products	Balanced?
C	1 × 1 = 1	1 × 1 = 1	1 = 1, yes
H	4 × 1 = 4	2 × 2 = 4	4 = 4, yes
O	2 × 2 = 4	(1 × 2) + (2 × 1) = 4	4 = 4, yes

A balanced chemical equation often may be derived from a qualitative description of some chemical reaction by a fairly simple approach known as balancing by inspection. Consider as an example the decomposition of water to yield molecular hydrogen and oxygen. This process is represented qualitatively by an *unbalanced* chemical equation:

$$\text{H}_2\text{O} \longrightarrow \text{H}_2 + \text{O}_2\ \text{(unbalanced)}$$

Comparing the number of H and O atoms on either side of this equation confirms its imbalance:

Tally Chart for Decomposition of Water to Yield Hydrogen and Oxygen #1

Element	Reactants	Products	Balanced?
H	1 × 2 = 2	1 × 2 = 2	2 = 2, yes
O	1 × 1 = 1	1 × 2 = 2	1 ≠ 2, no

The numbers of H atoms on the reactant and product sides of the equation are equal, but the numbers of O atoms are not. To achieve balance, the *coefficients* of the equation may be changed as needed. Keep in mind, of course, that the *formula subscripts* define, in part, the identity of the substance, and so these cannot be changed without altering the qualitative meaning of the equation. For example, changing the reactant formula from H_2O to H_2O_2 would yield balance in the number of atoms, but doing so also changes the reactant's identity (it's now hydrogen peroxide and not water). The O atom balance may be achieved by changing the coefficient for H_2O to 2.

$$2\ \mathrm{H_2O} \longrightarrow \mathrm{H_2} + \mathrm{O_2}\ \ \text{(unbalanced)}$$

Tally Chart for Decomposition of Water to Yield Hydrogen and Oxygen #2

Element	Reactants	Products	Balanced?
H	**2** × 2 = 4	1 × 2 = 2	4 ≠ 2, no
O	2 × 1 = 2	1 × 2 = 2	2 = 2, yes

The H atom balance was upset by this change, but it is easily reestablished by changing the coefficient for the H_2 product to 2.

$$2\ \mathrm{H_2O} \longrightarrow 2\ \mathrm{H_2} + \mathrm{O_2}\ \ \text{(balanced)}$$

Tally Chart for Decomposition of Water to Yield Hydrogen and Oxygen #3

Element	Reactants	Products	Balanced?
H	2 × 2 = 4	**2** × 2 = 4	4 = 4, yes
O	2 × 1 = 2	1 × 2 = 2	2 = 2, yes

These coefficients yield equal numbers of both H and O atoms on the reactant and product sides, and the balanced equation is, therefore:

$$2\ \mathrm{H_2O} \longrightarrow 2\ \mathrm{H_2} + \mathrm{O_2}$$

Example 8.1a

Balancing Chemical Equations

Write a balanced equation for the reaction of molecular nitrogen (N_2) and oxygen (O_2) to form dinitrogen pentoxide.

Solution

First, write the unbalanced equation.

$$N_2 + O_2 \longrightarrow N_2O_5 \text{ (unbalanced)}$$

Next, count the number of each type of atom present in the unbalanced equation.

Tally Chart for Reaction of Nitrogen and Oxygen to Form Dinitrogen Pentoxide #1

Element	Reactants	Products	Balanced?
N	1 × 2 = 2	1 × 2 = 2	2 = 2, yes
O	1 × 2 = 2	1 × 5 = 5	2 ≠ 5, no

Though nitrogen is balanced, changes in coefficients are needed to balance the number of oxygen atoms. To balance the number of oxygen atoms, a reasonable first attempt would be to change the coefficients for the O_2 and N_2O_5 to integers that will yield 10 O atoms (the least common multiple for the O atom subscripts in these two formulas).

$$N_2 + 5\ O_2 \longrightarrow 2\ N_2O_5 \text{ (unbalanced)}$$

Tally Chart for Reaction of Nitrogen and Oxygen to Form Dinitrogen Pentoxide #2

Element	Reactants	Products	Balanced?
N	1 ×× 2 = 2	**2** × 2 = 4	2 ≠ 4, no
O	**5** × 2 = 10	**2** × 5 = 10	10 = 10, yes

The N atom balance has been upset by this change; it is restored by changing the coefficient for the reactant N_2 to 2.

$$2\ N_2 + 5\ O_2 \longrightarrow 2\ N_2O_5$$

Tally Chart for Reaction of Nitrogen and Oxygen to Form Dinitrogen Pentoxide #3

Element	Reactants	Products	Balanced?
N	**2** × 2 = 4	2 × 2 = 4	4 = 4, yes
O	5 × 2 = 10	2 × 5 = 10	10 = 10, yes

The numbers of N and O atoms on either side of the equation are now equal, and so the equation is balanced.

Exercise 8.1a

Write a balanced equation for the decomposition of ammonium nitrate to form molecular nitrogen, molecular oxygen, and water. (Hint: Balance oxygen last, since it is present in more than one molecule on the right side of the equation.)

Check Your Answer[1]

It is sometimes convenient to use fractions instead of integers as intermediate coefficients in the process of balancing a chemical equation. When balance is achieved, all the equation's coefficients may then be multiplied by a whole number to convert the fractional coefficients to integers without upsetting the atom balance. For example, consider the reaction of ethane (C_2H_6) with oxygen to yield H_2O and CO_2, represented by the unbalanced equation:

$$C_2H_6 + O_2 \longrightarrow H_2O + CO_2 \text{ (unbalanced)}$$

Following the usual inspection approach, one might first balance C and H atoms by changing the coefficients for the two product species, as shown:

$$C_2H_6 + O_2 \longrightarrow 3\ H_2O + 2\ CO_2 \text{ (unbalanced)}$$

This results in seven O atoms on the product side of the equation, an odd number – no integer coefficient can be used with the O_2 reactant to yield an odd number, so a fractional coefficient, $\frac{7}{2}$, is used instead to yield a provisional balanced equation:

$$C_2H_6 + \frac{7}{2}O_2 \longrightarrow 3\ H_2O + 2\ CO_2$$

A conventional balanced equation with integer-only coefficients is derived by multiplying each coefficient by 2:

$$2\ C_2H_6 + 7\ O_2 \longrightarrow 6\ H_2O + 4\ CO_2$$

Finally with regard to balanced equations, recall that convention dictates use of the *smallest whole-number coefficients*. Although the equation for the reaction between molecular nitrogen and molecular hydrogen to produce ammonia is, indeed, balanced,

$$3\ N_2 + 9\ H_2 \longrightarrow 6\ NH_3$$

the coefficients are not the smallest possible integers representing the relative numbers of reactant and product molecules. Dividing each coefficient by the greatest common factor, 3, gives the preferred equation:

$$N_2 + 3\ H_2 \longrightarrow 2\ NH_3$$

Additional Information in Chemical Equations

The physical states of reactants and products in chemical equations very often are indicated with a parenthetical abbreviation following the formulas. Common abbreviations include *s* for solids, *l* for liquids, *g* for gases, and *aq* for substances dissolved in water (*aqueous solutions*, as introduced in the preceding chapter). These notations are illustrated in the example equation here:

$$2\ Na(s) + 2\ H_2O(l) \longrightarrow 2\ NaOH(aq) + H_2(g)$$

This equation represents the reaction that takes place when sodium metal is placed in water. The solid sodium reacts with liquid water to produce molecular hydrogen gas and the ionic compound sodium hydroxide (a solid in pure form, but readily dissolved in water).

Special conditions necessary for a reaction are sometimes designated by writing a word or symbol above or below the equation's arrow. For example, a reaction carried out by heating may be indicated by the uppercase Greek letter delta (Δ) over the arrow.

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

Endothermic vs. Exothermic Reactions

Sometimes ΔH for a chemical reaction is displayed which may be positive or negative. The number is assumed to be positive if it has no sign; a + sign can be added explicitly to avoid confusion. A chemical reaction that has a positive ΔH is said to be **endothermic** while a chemical reaction that has a negative ΔH is said to be **exothermic.**

What does it mean if the ΔH of a process is positive? It means that the system in which the chemical reaction is occurring is gaining energy. If one considers the energy of a system as being represented as a height on a vertical energy plot, the enthalpy change that accompanies the reaction can be shown in Figure 8.1c. It displays the energy of the reactants with some energy, and the system increases its energy as it goes to products. The products are higher on the vertical scale than the reactants. Endothermic, then, implies that the system *gains*, or absorbs, energy.

An opposite situation exists for an exothermic process, as shown in Figure 8.1d. If the ΔH of a reaction is negative, the system is losing energy, so the products have less energy than the reactants, and the products are lower on the vertical energy scale than the reactants are. Exothermic, then, implies that the system *loses*, or gives off, energy.

Source: "Endothermic vs. Exothermic Reactions" adapted by Adrienne Richards from Chapter 7: Enthalpy and Chemical Reactions (https://opentextbc.ca/introductorychemistry/chapter/enthalpy-and-chemical-reactions/) In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY NC SA 4.0.

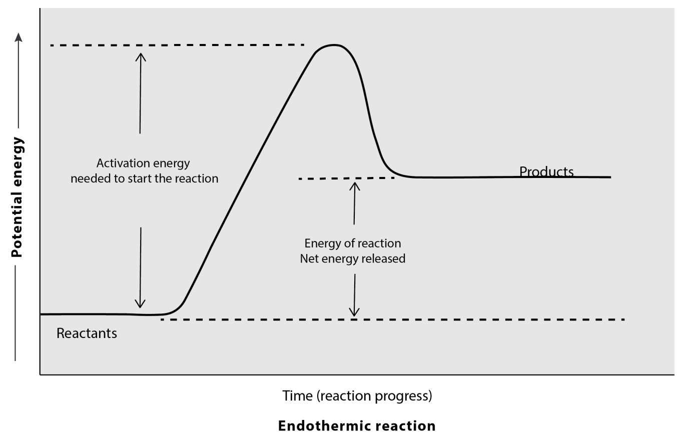

Figure 8.1c: The diagram depicts the change in potential energies as the reaction progresses over time for endothermic reactions. (credit: graphics by Revathi Mahadevan, CC BY 4.0)

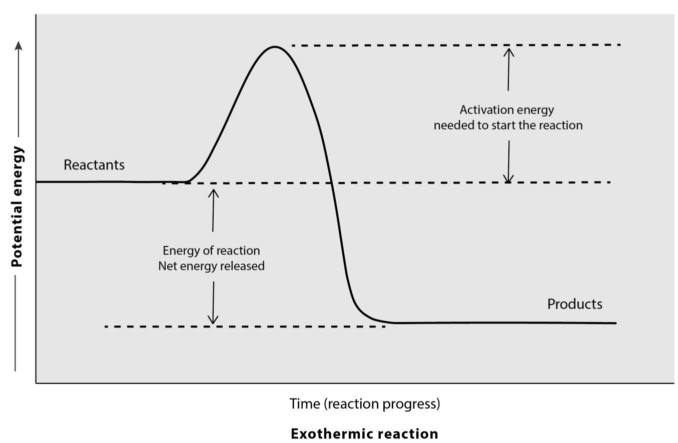

Figure 8.1d: The diagram depicts the change in potential energies as the reaction progresses over time for exothermic reactions. (credit: graphics by Revathi Mahadevan, CC BY 4.0)

Exercise 8.1b

Practice using the following PhET simulation: Balancing Chemical Equations (https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html)

Links to Interactive Learning Tools

Practice Balancing Chemical Equations (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Balancing-Chemical-Equations) from the Physics Classroom (https://www.physicsclassroom.com/).

Practice Writing Balanced Equations (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Writing-Chemical-Equations) from the Physics Classroom (https://www.physicsclassroom.com/).

Practice Particles, Words and Formulas (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Particles-Words-Formulas) from the Physics Classroom (https://www.physicsclassroom.com/).

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- "7.1 Writing and Balancing Chemical Equations (https://boisestate.pressbooks.pub/chemistry/chapter/7-1-writing-and-balancing-chemical-equations/)" In *General Chemistry 1 & 2* by Rice University, a derivative of *Chemistry (Open Stax)* by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson and is licensed under CC BY 4.0. Access for free at *Chemistry (OpenStax) (https://openstax.org/books/chemistry/pages/1-introduction)*
- Chapter 7: Enthalpy and Chemical Reactions (https://opentextbc.ca/introductorychemistry/chapter/enthalpy-and-chemical-reactions/) In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball

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Notes

1. $2\ NH_4NO_3 \longrightarrow 2\ N_2 + O_2 + 4\ H_2O$

8.2 CLASSIFYING COMPOSITION, DECOMPOSITION, AND COMBUSTION REACTIONS

Learning Objectives

By the end of this section, you will be able to:

- Identify composition, decomposition, and combustion reactions.
- Predict the products of a combustion reaction.

Three classifications of chemical reactions will be reviewed in this section – composition, decomposition and combustion – while two additional chemical reactions (single and double displacement) will be explored in the proceeding section. Predicting the products in some of them may be difficult, but the reactions are still easy to recognize.

Watch Types of Chemical Reactions (5 mins) (https://www.youtube.com/watch?v=TX6BYceUSL0)

A **composition reaction** (sometimes also called a *combination reaction* or a *synthesis reaction*) produces a single substance from multiple reactants. A single substance as a product is the key characteristic of the composition reaction. There may be a coefficient other than one for the substance, but if the reaction has only a single substance as a product, it can be called a composition reaction. In the reaction

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

water is produced from hydrogen and oxygen. Although there are two molecules of water being produced, there is only one substance – water – as a product. So this is a composition reaction.

A **decomposition reaction** starts from a single substance and produces more than one substance; that is, it decomposes. One substance as a reactant and more than one substance as the products is the key characteristic of a decomposition reaction. For example, if we look at the decomposition of sodium hydrogen carbonate (also known as sodium bicarbonate):

$$2\ NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(\ell)$$

We can see that sodium carbonate, carbon dioxide, and water are produced from the single substance sodium hydrogen carbonate.

Composition and decomposition reactions are difficult to predict; however, they should be easy to recognize.

Example 8.2a

Problems

Identify each equation as a composition reaction, a decomposition reaction, or neither.

1. $Fe_2O_3 + 3\ SO_3 \rightarrow Fe_2(SO_4)_3$
2. $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$
3. $(NH_4)_2Cr_2O_7 \rightarrow Cr_2O_3 + 4\ H_2O + N_2$

Solutions

1. In this equation, two substances combine to make a single substance. This is a composition reaction.
2. Two different substances react to make two new substances. This does not fit the definition of either a composition reaction or a decomposition reaction, so it is neither. In fact, you may recognize this as a double-replacement reaction.
3. A single substance reacts to make multiple substances. This is a decomposition reaction.

Exercise 8.2a

Identify the equation as a composition reaction, a decomposition reaction, or neither.

$$C_3H_8 \rightarrow C_3H_4 + 2\ H_2$$

Check Your Answer[1]

A **combustion reaction** occurs when a reactant combines with oxygen, many times from the atmosphere, to produce oxides of all other elements as products; any nitrogen in the reactant is converted to elemental nitrogen, N_2. Many reactants, called *fuels*, contain mostly carbon and hydrogen atoms, reacting with oxygen to produce CO_2 and H_2O. For example, the balanced chemical equation for the combustion of methane, CH_4, is as follows:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Kerosene can be approximated with the formula $C_{12}H_{26}$, and its combustion equation is

$$2\ C_{12}H_{26} + 37\ O_2 \rightarrow 24\ CO_2 + 26\ H_2O$$

Sometimes fuels contain oxygen atoms, which must be counted when balancing the chemical equation. One common fuel is ethanol, C_2H_5OH, whose combustion equation is

$$C_2H_5OH + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$$

If nitrogen is present in the original fuel, it is converted to N_2, not to a nitrogen-oxygen compound. Thus, for the combustion of the fuel dinitroethylene, whose formula is $C_2H_2N_2O_4$, we have

$$2\ C_2H_2N_2O_4 + O_2 \rightarrow 4\ CO_2 + 2\ H_2O + 2\ N_2$$

Example 8.2b

Problems

Complete and balance each combustion equation.

1. the combustion of propane, C_3H_8 (Figure 8.2a)
2. the combustion of ammonia, NH_3

Solutions

1. The products of the reaction are CO_2 and H_2O, so our unbalanced equation is $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$. Balancing (and you may have to go back and forth a few times to balance this), we get $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$.
2. The nitrogen atoms in ammonia will react to make N_2, while the hydrogen atoms will react with O_2 to make H_2O, thus $NH_3 + O_2 \rightarrow N_2 + H_2O$. To balance this equation without fractions (which is the convention), we get $4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O$.

Figure 8.2a: Propane is a fuel used to provide heat for some homes. Propane is stored in large tanks like that shown here. (credit: work by vistavision, CC BY-NC-ND 2.0

Exercise 8.2b

Complete and balance the combustion equation for cyclopropanol, C_3H_6O.

Check Your Answer[2]

Attribution & References

Except where otherwise noted, this section is adapted by Adrienne Richards from "Chemical Reactions and Equations: Composition, Decomposition, and Combustion Reactions (https://opentextbc.ca/introductorychemistry/part/chapter-4-chemical-reactions-and-equations/)" In *Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0.

Notes

1. Decomposition
2. $C_3H_6O + 4\ O_2 \rightarrow 3\ CO_2 + 3\ H_2O$

8.3 CLASSIFYING AND COMPLETING SINGLE AND DOUBLE DISPLACEMENT REACTIONS

Learning Objectives

By the end of this section, you will be able to:

- Identify chemical reactions as single displacement reactions and double displacement reactions
- Use the periodic table, an activity series, or solubility rules to predict whether single displacement reactions or double displacement reactions will occur

Indigenous Perspective: Natural Chemical Reactions

Figure 8.3a: Birch tree (credit: work by Dallas Reedy, Unsplash license)

Chemical reactions related to Indigenous practices in Canada are used as a teaching tool, described within the document "Chemical Reactions: Background Information Science 10 [PDF] (https://www.stf.sk.ca/wp-content/uploads/2015/10/s106_4.pdf)".

The teaching tool was developed in collaboration with the Steward Resources Center, the Government of Saskatchewan and the Saskatchewan Teachers' Federation.

Chemical reactions are involved in practices passed down from one generation to the next. This is important so that First Nations and

Metis communities can make their own supplies by following the methods from previous generations. These practices include the process of making natural bleach, jellies, medicines, meals and household products.

Up to now, we have presented chemical reactions as a topic, but we have not discussed how the products of a chemical reaction can be predicted. Here we will begin our study of certain types of chemical reactions that allow us to predict what the products of the reaction will be.

A **single displacement reaction** is a chemical reaction in which one element is substituted for another element in a compound, generating a new element and a new compound as products. For example:

$$2\ HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$$

is an example of a single displacement reaction. The hydrogen atoms in HCl are replaced by Zn atoms, and in the process a new element – hydrogen – is formed. Another example of a single displacement reaction is:

$$2\ NaCl(aq) + F_2(g) \rightarrow 2\ NaF(s) + Cl_2(g)$$

Here the negatively charged ion changes from chloride to fluoride. A typical characteristic of a single displacement reaction is that there is one element as a reactant and another element as a product.

Not all proposed single displacement reactions will occur between two given reactants. This is most easily demonstrated with fluorine, chlorine, bromine, and iodine. Collectively, these elements are called the *halogens* and are in the next-to-last column on the periodic table (see Figure 8.3b). The elements on top of the column will replace the elements below them on the periodic table but not the other way around. Thus, the reaction represented by:

$$CaI_2(s) + Cl_2(g) \rightarrow CaCl_2(s) + I_2(s)$$

This reaction will occur, but the reaction

$$CaF_2(s) + Br_2(\ell) \rightarrow CaBr_2(s) + F_2(g)$$

will not because bromine is below fluorine on the periodic table. This is just one of many ways the periodic table helps us understand chemistry.

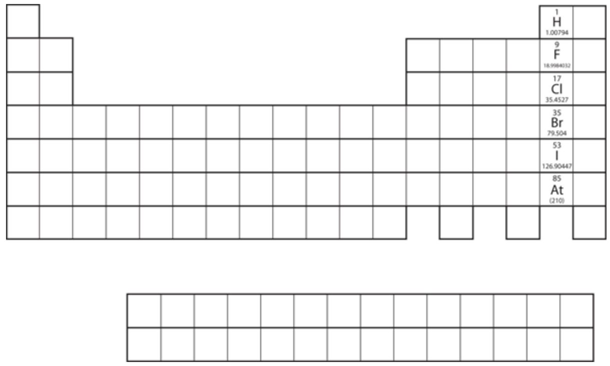

Figure 8.3b: "Halogens on the Periodic Table." The halogens are the elements in the next-to-last column on the periodic table. Review the Periodic Table of the Elements in other formats in Appendix A (credit: *Introductory Chemistry: 1st Canadian Edition*, CC BY-NC-SA 4.0).

Example 8.3a

Problems

Will a single-replacement reaction occur? If so, identify the products.

1. $MgCl_2 + I_2 \rightarrow ?$
2. $CaBr_2 + F_2 \rightarrow ?$

Solutions

1. Because iodine is below chlorine on the periodic table, a single-replacement reaction will not occur.
2. Because fluorine is above bromine on the periodic table, a single-replacement reaction will occur, and the products of the reaction will be CaF_2 and Br_2.

Exercise 8.3a

Will a single-replacement reaction occur? If so, identify the products.

$$FeI_2 + Cl_2 \rightarrow ?$$

Check Your Answer[1]

Chemical reactivity trends are easy to predict when replacing anions in simple ionic compounds – simply use their relative positions on the periodic table. However, when replacing the cations, the trends are not as straightforward. This is partly because there are so many elements that can form cations; an element in one column on the periodic table may replace another element nearby, or it may not. A list called the **activity series** does the same thing the periodic table does for halogens: it lists the elements that will replace elements below them in single-replacement reactions. A simple activity series is shown below.

Activity Series for Cation Replacement in Single Displacement Reactions

1. Li
2. K
3. Ba
4. Sr
5. Ca
6. Na
7. Mg
8. Al
9. Mn
10. Zn
11. Cr
12. Fe
13. Ni
14. Sn
15. Pb
16. H_2
17. Cu
18. Hg
19. Ag
20. Pd
21. Pt
22. Au

An element with a lower number will replace an element with a higher number in compounds undergoing a single displacement reaction. Elements will not replace elements with a lower number in compounds. In many sources, these elements are listed as a long vertical list (not numbered).

Using the activity series is similar to using the positions of the halogens on the periodic table. An element on top will replace an element below it in compounds undergoing a single displacement reaction. Elements will not replace elements above them in compounds.

Example 8.3b

Problems

Use the activity series to predict the products, if any, of each equation.

1. $FeCl_2$ + Zn → ?
2. HNO_3 + Au → ?

Solutions

1. Because zinc is above iron in the activity series, it will replace iron in the compound. The products of this single displacement reaction are $ZnCl_2$ and Fe.
2. Gold is below hydrogen in the activity series. As such, it will not replace hydrogen in a compound with the nitrate ion. No reaction is predicted.

Exercise 8.3b

Use the activity series to predict the products, if any, of this equation.

$$AlPO_4 + Mg \rightarrow ?$$

Check Your Answer[2]

A **double displacement reaction** occurs when parts of two ionic compounds are exchanged, making two new compounds. A characteristic of a double displacement equation is that there are two compounds as reactants and two different compounds as products.

Evidence of a double replacement reaction are the following:

1. The evolution of heat
2. The formation of an insoluble precipitate

3. The production of gas bubbles

Source: (Hein et al., 2013, p. 153)

An example of a double displacement reaction is:

$$CuCl_2(aq) + 2\ AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ AgCl(s)$$

There are two equivalent ways of considering a double displacement equation: either the cations are swapped, or the anions are swapped. (You cannot swap both; you would end up with the same substances you started with.) Either perspective should allow you to predict the proper products, as long as you pair a cation with an anion and not a cation with a cation or an anion with an anion.

Example 8.3c

Problem

Predict the products of this double displacement equation: $BaCl_2 + Na_2SO_4 \rightarrow ?$

Solution

Thinking about the reaction as either switching the cations or switching the anions, we would expect the products to be $BaSO_4$ and NaCl.

Exercise 8.3c

Predict the products of this double displacement equation: $KBr + AgNO_3 \rightarrow ?$

Check Your Answer[3]

Predicting whether a double displacement reaction occurs is somewhat more difficult than predicting a single displacement reaction. However, there is one type of double displacement reaction that we can predict: the precipitation reaction. A **precipitation reaction** occurs when two ionic compounds are dissolved in water and form a new ionic compound that does not dissolve; this new compound falls out of solution as a solid **precipitate**. The formation of a solid precipitate is the driving force that makes the reaction proceed.

For example, consider the double displacement reaction between Na_2SO_4 and $SrCl_2$. The double displacement reaction products are NaCl and $SrSO_4$. The balanced chemical equation is:

$$Na_2SO_4(aq) + SrCl_2(aq) \rightarrow 2\ NaCl(aq) + SrSO_4(s)$$

You would expect to see a visual change corresponding to $SrSO_4$ precipitating out of solution as noted by the (s) in the product formed within the chemical equation (Figure 8.3c).

Figure 8.3c: "Double Displacement Reactions." Some double displacement reactions are obvious because you can see a solid precipitate coming out of the solution. (credit: work by Choij, PD)

General examples of double displacement reactions include:

- Neutralization of an Acid and a Base (heat is released by the production of water)

  Example: \ce{HCl (aq) + NaOH (aq) → NaCl (aq) + H2O (l)}

- Metal Oxide + Acid (heat is released by the production of water)

  Example: $\mathrm{CuO + 2\,HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + H_2O(l)}$

- Formation of an Insoluble Precipitate (precipitate is formed as indicated by the (s) in the product)

  Example: $\mathrm{BaCl_2(aq) + 2\,AgNO_3(aq) \rightarrow 2\,AgCl(s) + Ba(NO_3)_2(aq)}$

- Formation of a Gas (a gas is formed as indicated by the (g) in the product).

  Example: $\mathrm{H_2SO_4(aq) + NaCl(s) \rightarrow NaHSO_4(s) + HCl(g)}$

Source: (Hein et al., 2013, p. 153)

Example 8.3d

Problem

What are the products of the double displacement reaction

1. $NaOH + FeCl_2 \rightarrow ?$

Solution

1. The balanced chemical equation is: $2\ NaOH(aq) + FeCl_2(aq) \rightarrow 2\ NaCl(aq) + Fe(OH)_2(s)$

Exercise 8.3d

Check Your Learning Exercise (Text Version)
For the following reactions, classify the reaction as one of the following: single displacement, decomposition, combination, double displacement, or combustion.

a. $2CH_3OH\ (g) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 4H_2O\ (g)$
b. $2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$
c. $P_4\ (s) + 5O_2\ (g) \rightarrow P_4O_{10}\ (s)$
d. $2Al\ (s) + 3H_2SO_4\ (aq) \rightarrow Al_2(SO_4)_3\ (s) + 3H_2\ (g)$
e. $ZnS\ (s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2S\ (g)$

Check Your Answer[4]

Source: "Exercise 8.3d" by Adrienne Richards is adapted from "7.2 Classifying Chemical Reactions" from General Chemistry 1 & 2, a derivative of Chemistry (Open Stax) by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson, licensed under CC BY 4.0.

Links to Interactive Learning Tools

Practice Chemical Reaction Types (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Reaction-Types) from the Physics Classroom (https://www.physicsclassroom.com/).

Practice Writing Chemical Equations (https://www.physicsclassroom.com/Concept-Builders/Chemistry/Writing-Chemical-Equations) from the Physics Classroom (https://www.physicsclassroom.com/).

Attribution & References

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Reference

Hein, M., Pattison, S., Arena, S., & Best, L. (2013). *Introduction to general, organic, and biochemistry* (11th ed.). John Wiley & Sons, Inc.

Notes

1. Yes; $FeCl_2$ and I_2
2. $Mg_3(PO_4)_2$ and Al
3. KNO_3 and AgBr
4. (a) combustion; (b) decomposition; (c) combination; (d) single displacement; (e)double displacement

CHAPTER 8 - SUMMARY

8.1 Writing and Balancing Chemical Equations

Chemical equations are symbolic representations of chemical and physical changes. Formulas for the substances undergoing the change (reactants) and substances generated by the change (products) are separated by an arrow and preceded by integer coefficients indicating their relative numbers. Balanced equations are those whose coefficients result in equal numbers of atoms for each element in the reactants and products.

8.2 Classifying Composition, Decomposition and Combustion Reactions

Three types of chemical reactions were learned: a composition reaction, a decomposition reaction and a combustion reaction. A composition reaction produces a single substance from multiple reactants. A decomposition reaction produces multiple products from a single reactant. Combustion reactions are the combination of some compound with oxygen to make oxides of the other elements as products (although nitrogen atoms react to make N_2).

8.3 Classifying and Completing Single and Double Displacement Reactions

Two types of chemical reactions were learned: single displacement and double displacement. A single displacement reaction replaces one element for another in a compound. The periodic table or an activity series can help predict whether single displacement reactions occur. A double displacement reaction exchanges the cations (or the anions) of two ionic compounds. A precipitation reaction is a double displacement reaction in which one product is a solid precipitate.

Attribution & References

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- 8.1 – "Summary 4.1. Writing and Balancing Chemical Equations (https://openstax.org/books/chemistry-2e/pages/4-summary)" in *Chemistry 2e (OpenStax)* by Paul Flowers, Klaus Theopold, Richard Langley, & William R. Robinson, licensed under CC BY 4.0. Access for free at Chemistry 2e (OpenStax) (https://openstax.org/details/books/chemistry-2e).
- 8.2 and 8.3 – "Chapter 4: Chemical Reactions and Equations: Composition, Decomposition, and Combustion Reactions" (https://opentextbc.ca/introductorychemistry/part/chapter-3-atoms-molecules-and-ions/)and "Chapter 4: Types of Chemical Reactions: Single and Double Displacement Reactions (https://opentextbc.ca/introductorychemistry/chapter/types-of-chemical-reactions-single-and-double-displacement-reactions/)" In*Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0.

CHAPTER 8 - REVIEW

8.1 Writing and Balancing Chemical Equations

1. What does it mean to say an equation is balanced? Why is it important for an equation to be balanced? **Check Answer:** [1]
2. Balance the following equations: **Check Answer:** [2]
   a. $PCl_5(s) + H_2O(l) \longrightarrow POCl_3(l) + HCl(aq)$
   b. $Cu(s) + HNO_3(aq) \longrightarrow Cu(NO_3)_2(aq) + H_2O(l) + NO(g)$
   c. $H_2(g) + I_2(s) \longrightarrow HI(s)$
   d. $Fe(s) + O_2(g) \longrightarrow Fe_2O_3(s)$
   e. $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$
   f. $(NH_4)_2Cr_2O_7(s) \longrightarrow Cr_2O_3(s) + N_2(g) + H_2O(g)$
   g. $P_4(s) + Cl_2(g) \longrightarrow PCl_3(l)$
   h. $PtCl_4(s) \longrightarrow Pt(s) + Cl_2(g)$
3. Balance the following equations:
   a. $Ag(s) + H_2S(g) + O_2(g) \longrightarrow Ag_2S(s) + H_2O(l)$
   b. $P_4(s) + O_2(g) \longrightarrow P_4O_{10}(s)$
   c. $Pb(s) + H_2O(l) + O_2(g) \longrightarrow Pb(OH)_2(s)$
   d. $Fe(s) + H_2O(l) \longrightarrow Fe_3O_4(s) + H_2(g)$
   e. $Sc_2O_3(s) + SO_3(l) \longrightarrow Sc_2(SO_4)_3(s)$
   f. $Ca_3(PO_4)_2(aq) + H_3PO_4(aq) \longrightarrow Ca(H_2PO_4)_2(aq)$
   g. $Al(s) + H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(s) + H_2(g)$
   h. $TiCl_4(s) + H_2O(g) \longrightarrow TiO_2(s) + HCl(g)$
4. Write a balanced molecular equation describing each of the following chemical reactions. **Check Answer:** [3]
   a. Solid calcium carbonate is heated and decomposes to solid calcium oxide and carbon dioxide gas.
   b. Gaseous butane, C_4H_{10}, reacts with diatomic oxygen gas to yield gaseous carbon dioxide and water vapour.
   c. Aqueous solutions of magnesium chloride and sodium hydroxide react to produce solid magnesium hydroxide and aqueous sodium chloride.
   d. Water vapour reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.
5. Write a balanced equation describing each of the following chemical reactions.
   a. Solid potassium chlorate, $KClO_3$, decomposes to form solid potassium chloride and diatomic

oxygen gas.

b. Solid aluminum metal reacts with solid diatomic iodine to form solid Al_2I_6.
c. When solid sodium chloride is added to aqueous sulfuric acid, hydrogen chloride gas and aqueous sodium sulfate are produced.
d. Aqueous solutions of phosphoric acid and potassium hydroxide react to produce aqueous potassium dihydrogen phosphate and liquid water.

6. Colourful fireworks often involve the decomposition of barium nitrate and potassium chlorate and the reaction of the metals magnesium, aluminum, and iron with oxygen. **Check Answer:** [4]
   a. Write the formulas of barium nitrate and potassium chlorate.
   b. The decomposition of solid potassium chlorate leads to the formation of solid potassium chloride and diatomic oxygen gas. Write an equation for the reaction.
   c. The decomposition of solid barium nitrate leads to the formation of solid barium oxide, diatomic nitrogen gas, and diatomic oxygen gas. Write an equation for the reaction.
   d. Write separate equations for the reactions of the solid metals magnesium, aluminum, and iron with diatomic oxygen gas to yield the corresponding metal oxides. (Assume the iron oxide contains Fe^{3+} ions.)

8.2 Classifying Composition, Decomposition and Combustion Reactions

1. Which is a composition reaction and which is not? **Check Answer:** [5]
   a. $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$
   b. $CaO + CO_2 \rightarrow CaCO_3$
2. Which is a composition reaction and which is not?
   a. $H_2 + Cl_2 \rightarrow 2\,HCl$
   b. $2\,HBr + Cl_2 \rightarrow 2\,HCl + Br_2$
3. Which is a composition reaction and which is not? **Check Answer:** [6]
   a. $2\,SO_2 + O_2 \rightarrow 2\,SO_3$
   b. $6\,C + 3\,H_2 \rightarrow C_6H_6$
4. Which is a composition reaction and which is not?
   a. $4\,Na + 2\,C + 3\,O_2 \rightarrow 2\,Na_2CO_3$
   b. $Na_2CO_3 \rightarrow Na_2O + CO_2$
5. Which is a decomposition reaction and which is not? **Check Answer:** [7]
   a. $HCl + NaOH \rightarrow NaCl + H_2O$
   b. $CaCO_3 \rightarrow CaO + CO_2$
6. Which is a decomposition reaction and which is not?
   a. $3\,O_2 \rightarrow 2\,O_3$

b. $2\ KClO_3 \rightarrow 2\ KCl + 3\ O_2$

7. Which is a decomposition reaction and which is not? **Check Answer:** [8]
   a. $Na_2O + CO_2 \rightarrow Na_2CO_3$
   b. $H_2SO_3 \rightarrow H_2O + SO_2$
8. Which is a decomposition reaction and which is not?
   a. $2\ C_7H_5N_3O_6 \rightarrow 3\ N_2 + 5\ H_2O + 7\ CO + 7\ C$
   b. $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
9. Which is a combustion reaction and which is not? **Check Answer:** [9]
   a. $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
   b. $2\ Fe_2S_3 + 9\ O_2 \rightarrow 2\ Fe_2O_3 + 6\ SO_2$
10. Which is a combustion reaction and which is not?
    a. $CH_4 + 2\ F_2 \rightarrow CF_4 + 2\ H_2$
    b. $2\ H_2 + O_2 \rightarrow 2\ H_2O$
11. Which is a combustion reaction and which is not? **Check Answer:** [10]
    a. $P_4 + 5\ O_2 \rightarrow 2\ P_2O_5$
    b. $2\ Al_2S_3 + 9\ O_2 \rightarrow 2\ Al_2O_3 + 6\ SO_2$
12. Which is a combustion reaction and which is not?
    a. $C_2H_4 + O_2 \rightarrow C_2H_4O_2$
    b. $C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$
13. Is it possible for a composition reaction to also be a combustion reaction? Give an example to support your case. **Check Answer:** [11]
14. Is it possible for a decomposition reaction to also be a combustion reaction? Give an example to support your case.
15. Complete and balance each combustion equation. **Check Answer:** [12]
    a. $C_4H_9OH + O_2 \rightarrow ?$
    b. $CH_3NO_2 + O_2 \rightarrow ?$
16. Complete and balance each combustion equation.
    a. $B_2H_6 + O_2 \rightarrow ?$ (The oxide of boron formed is B_2O_3.)
    b. $Al_2S_3 + O_2 \rightarrow ?$ (The oxide of sulfur formed is SO_2.)
    c. $Al_2S_3 + O_2 \rightarrow ?$ (The oxide of sulfur formed is SO_3.)

8.3 Classifying and Completing Single- and Double-Displacement Reactions

1. What are the general characteristics that help you recognize single-replacement reactions? **Check Answer:** [13]
2. What are the general characteristics that help you recognize double-replacement reactions?

3. Assuming that each single-replacement reaction occurs, predict the products and write each balanced chemical equation. **Check Answer:** [14]
   a. $Zn + Fe(NO_3)_2 \rightarrow ?$
   b. $F_2 + FeI_3 \rightarrow ?$
4. Assuming that each single-replacement reaction occurs, predict the products and write each balanced chemical equation.
   a. $Li + MgSO_4 \rightarrow ?$
   b. $NaBr + Cl_2 \rightarrow ?$
5. Assuming that each single-replacement reaction occurs, predict the products and write each balanced chemical equation. **Check Answer:** [15]
   a. $Sn + H_2SO_4 \rightarrow ?$
   b. $Al + NiBr_2 \rightarrow ?$
6. Assuming that each single-replacement reaction occurs, predict the products and write each balanced chemical equation.
   a. $Mg + HCl \rightarrow ?$
   b. $HI + Br_2 \rightarrow ?$
7. Use the periodic table or the activity series to predict if each single-replacement reaction will occur and, if so, write a balanced chemical equation. **Check Answer:** [16]
   a. $FeCl_2 + Br_2 \rightarrow ?$
   b. $Fe(NO_3)_3 + Al \rightarrow ?$
8. Use the periodic table or the activity series to predict if each single-replacement reaction will occur and, if so, write a balanced chemical equation.
   a. $Zn + Fe_3(PO_4)_2 \rightarrow ?$
   b. $Ag + HNO_3 \rightarrow ?$
9. Use the periodic table or the activity series to predict if each single-replacement reaction will occur and, if so, write a balanced chemical equation. **Check Answer:** [17]
   a. $NaI + Cl_2 \rightarrow ?$
   b. $AgCl + Au \rightarrow ?$
10. Use the periodic table or the activity series to predict if each single-replacement reaction will occur and, if so, write a balanced chemical equation.
    a. $Pt + H_3PO_4 \rightarrow ?$
    b. $Li + H_2O \rightarrow ?$ (Hint: treat H_2O as if it were composed of H^+ and OH^- ions.)
11. Assuming that each double-replacement reaction occurs, predict the products and write each balanced chemical equation. **Check Answer:** [18]
    a. $Zn(NO_3)_2 + NaOH \rightarrow ?$
    b. $HCl + Na_2S \rightarrow ?$
12. Assuming that each double-replacement reaction occurs, predict the products and write each balanced

chemical equation.

a. $Ca(C_2H_3O_2)_2 + HNO_3 \rightarrow ?$
b. $Na_2CO_3 + Sr(NO_2)_2 \rightarrow ?$

13. Assuming that each double-replacement reaction occurs, predict the products and write each balanced chemical equation. **Check Answer:** [19]
    a. $Pb(NO_3)_2 + KBr \rightarrow ?$
    b. $K_2O + MgCO_3 \rightarrow ?$
14. Assuming that each double-replacement reaction occurs, predict the products and write each balanced chemical equation.
    a. $Sn(OH)_2 + FeBr_3 \rightarrow ?$
    b. $CsNO_3 + KCl \rightarrow ?$
15. Assuming that the double-replacement reaction occurs, predict the product and write a balanced chemical equation. **Check Answer:** [20]
    a. $Pb(NO_3)_2 + KBr \rightarrow ?$
16. Assuming that each double-replacement reaction occurs, predict the products and write each balanced chemical equation. **Check Answer:** [21]
    a. $K_3PO_4 + SrCl_2 \rightarrow ?$
    b. $NaOH + MgCl_2 \rightarrow ?$

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- "Exercises 4.1. Writing and Balancing Chemical Equations (https://openstax.org/books/chemistry-2e/pages/4-exercises)" in *Chemistry 2e (OpenStax)* by Paul Flowers, Klaus Theopold, Richard Langley, & William R. Robinson, licensed under CC BY 4.0. Access for free at Chemistry 2e (OpenStax) (https://openstax.org/details/books/chemistry-2e?Book%20details). Questions 1-7.
- "Chapter 4: Chemical Reactions and Equations: Composition, Decomposition, and Combustion Reactions" (https://opentextbc.ca/introductorychemistry/part/chapter-3-atoms-molecules-and-ions/)and "Chapter 4: Types of Chemical Reactions: Single and Double Displacement Reactions" In*Introductory Chemistry: 1st Canadian Edition* by David W. Ball and Jessica A. Key, licensed under CC BY-NC-SA 4.0. Questions 8-38.

Notes

1. An equation is balanced when the same number of each element is represented on the reactant and product sides.

Equations must be balanced to accurately reflect the law of conservation of matter.

2. (a) $PCl_5(s) + H_2O(l) \longrightarrow POCl_3(l) + 2HCl(aq)$; (b) $3Cu(s) + 8HNO_3(aq) \longrightarrow 3Cu(NO_3)_2(aq) + 4H_2O(l) + 2NO(g)$; (c) $H_2(g) + I_2(s) \longrightarrow 2HI(s)$; (d) $4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$; (e) $2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$; (f) $(NH_4)_2Cr_22O_7(s) \longrightarrow Cr_2O_3(s) + N_2(g) + 4H_2O(l)$; (g) $P_4(s) + 6Cl_2(g) \longrightarrow 4PCl_3(l)$; (h) $PtCl_4(s) \longrightarrow Pt(s) + 2Cl_2(g)$;
3. (a) $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$; (b) $2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$; (c) $MgCl_2(aq) + 2NaOH(aq) \longrightarrow Mg(OH)_2(s) + 2NaCl(aq)$; (d) $2H_2O(g) + 2Na(s) \longrightarrow 2NaOH(s) + H_2(g)$;
4. (a) $Ba(NO_3)_2$, $KClO_3$; (b) $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$; (c) $2Ba(NO_3)_2(s) \longrightarrow 2BaO(s) + 2N_2(g) + 5O_2(g)$; (d) $2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$; $4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(g)$; $4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$;
5. a. not composition; b. composition
6. a. composition; b. composition
7. a. not decomposition; b. decomposition
8. a. not decomposition; b. decomposition
9. a. combustion; b. combustion
10. a. combustion; b. combustion
11. Yes; $2 H_2 + O_2 \rightarrow 2 H_2O$ (answers will vary)
12. a. $C_4H_9OH + 6 O_2 \rightarrow 4 CO_2 + 5 H_2O$ b. $4 CH_3NO_2 + 3 O_2 \rightarrow 4 CO_2 + 6 H_2O + 2 N_2$
13. One element replaces another element in a compound.
14. a. $Zn + Fe(NO_3)_2 \rightarrow Zn(NO_3)_2 + Fe$ b. $3 F_2 + 2 FeI_3 \rightarrow 3 I_2 + 2 FeF_3$
15. a. $Sn + H_2SO_4 \rightarrow SnSO_4 + H_2$ b. $2 Al + 3 NiBr_2 \rightarrow 2 AlBr_3 + 3 Ni$
16. a. No reaction occurs. b. . $Fe(NO_3)_3 + Al \rightarrow Al(NO_3)_3 + Fe$
17. a. $2 NaI + Cl_2 \rightarrow 2 NaCl + I_2$ b. No reaction occurs.
18. a. $Zn(NO_3)_2 + 2 NaOH \rightarrow Zn(OH)_2 + 2 NaNO_3$ b. $2 HCl + Na_2S \rightarrow 2 NaCl + H_2S$
19. a. $Pb(NO_3)_2 + 2 KBr \rightarrow PbBr_2 + 2 KNO_3$ b. $K_2O + MgCO_3 \rightarrow K_2CO_3 + MgO$
20. . a. $Pb(NO_3)_2 + 2 KBr \rightarrow PbBr_2(s) + 2 KNO_3$
21. a. $2 K_3PO_4 + 3 SrCl_2 \rightarrow Sr_3(PO_4)_2(s) + 6 KCl$ b. $2 NaOH + MgCl_2 \rightarrow 2 NaCl + Mg(OH)_2(s)$