Formulas and Equations

TOPIC 2

How Scientists Communicate With Symbols

Which "water" would all scientists around the world understand?

l'eau

wasser

acqua

agua

H_2O

ماء

물

水

вода

ύδωρ

water

Find the answer in this topic.

TOPIC 2

Formulas and Equations

Vocabulary

analysis	exothermic	qualitative
chemical change	formula	quantitative
coefficient	molecular formula	reactant
decomposition	molecule	single replacement
diatomic molecule	physical change	subscript
double replacement	polyatomic ion	symbol
empirical formula	product	synthesis
endothermic		

Topic Overview

Chemists in every country of the world speak many different languages. Despite their language differences, it is necessary for them to communicate with each other in a clear and concise manner. Chemists have agreed to a universal language of symbols to identify the elements of the earth, and a system of formulas and equations to explain how the elements interact. In this topic you will explore how the symbols are used to identify the different elements and how they can be combined into formulas representing the millions of different compounds. Then you will learn how these formulas can be combined into chemical equations to show the quantitative and qualitative aspects of chemical reactions.

Chemical Symbols and Formulas

While the names of the elements are often different in various languages of the world, it is important that a person in any country can quickly and accurately determine which element is being referred to.

Chemical Symbols

A system for a universal shorthand to identify the elements has been agreed upon. Each element has been assigned a unique one-, two-, or three-letter **symbol** for its identification. The first letter of a symbol is always capitalized. If there are any other letters in the symbol, they are lower case.

Some of the more common elements have a single letter symbol, such as O for oxygen and H for hydrogen. Other elements have symbols with two letters. Only recently discovered elements that don't yet have permanent names are given three-letter symbols. These elements are given systematic names that represent their atomic number until a name can be agreed upon by the International Union of Pure and Applied Chemists (IUPAC).

Symbols are usually easy to remember, as the letters in the symbol often relate to the English name of the element, such as He for helium and Al for aluminum. Sometimes the letters of the symbol do not correspond to the common English element name but relate instead to the Latin or Greek name, such as K (Latin *kalium*) for potassium, and Na (Latin *natrium*) for sodium. Table 2-1 shows the names and symbols of elements with atomic numbers 1–20.

Table 2-1. Names and Symbols for the First 20 Elements

Atomic Number	Name	Symbol	Atomic Number	Name	Symbol
1	hydrogen	H	11	sodium	Na
2	helium	He	12	magnesium	Mg
3	lithium	Li	13	aluminum	Al
4	beryllium	Be	14	silicon	Si
5	boron	B	15	phosphorus	P
6	carbon	C	16	sulfur	S
7	nitrogen	N	17	chlorine	Cl
8	oxygen	O	18	argon	Ar
9	fluorine	F	19	potassium	K
10	neon	Ne	20	calcium	Ca

Diatomic Molecules When writing the symbols of uncombined elements, almost all are written as monatomic, that is, without a subscript. A **subscript** is a number to the right and slightly below a symbol that tells the number of atoms present. A subscript is not written if only one atom is present. Therefore, the symbol for iron is Fe, neon is Ne, and carbon is C.

There are, however, several important exceptions. Some elements exist in nature as two identical atoms covalently bonded into a **diatomic molecule.** Oxygen normally exists as O_2, a diatomic molecule. Other elements that exist as diatomic molecules are hydrogen (H_2), nitrogen (N_2), and the elements of Group 17 of the periodic table (F_2, Cl_2, Br_2, and I_2). Be sure that whenever you write the formulas for any of these uncombined elements, that you write them as diatomic molecules.

Chemical Formulas

Compounds are composed of combinations of elements chemically combined in definite proportions by weight (mass). **Formulas** use chemical symbols and numbers to show both qualitative and quantitative information about a substance. **Qualitative** information relates to things that cannot be counted or measured, such as what elements are in the compound. **Quantitative** information deals with things that can be either counted or measured, such as the number of atoms of each element present in a unit of the compound.

In a formula of a compound, the symbols for the elements supply the qualitative information. The formula CO tells the reader that the compound consists of carbon and oxygen. Notice the difference between CO and Co. The first is a combination of two elements in a compound, carbon monoxide, while the second is the symbol for an element, cobalt.

Carbon monoxide

CO

one carbon atom,
one oxygen atom

Carbon dioxide

CO_2

one carbon atom,
two oxygen atoms

Figure 2-1. Subscripts in a formula: The use of subscripts shows the relative number of atoms of each type in a compound. No subscript is written if only one atom of an element is present.

Recall that the numbers to the right and slightly below a symbol, called subscripts, supply quantitative information, telling us the number of atoms of those elements in a unit of the compound. For example, the symbols in the formula H_2SO_4 give us the qualitative information that the compound contains hydrogen, sulfur, and oxygen. The subscript 2 after the H indicates that there are two atoms of hydrogen present. No subscript is written after the S, so there is one sulfur atom. The 4 after O informs the reader that there are four atoms of oxygen present. Figure 2-1 shows the use of subscripts for the two compounds of carbon and oxygen. Table 2-2 shows some formulas for elements and compounds. Notice that the formula for a monatomic element is just its symbol.

Table 2-2. Formulas for Some Elements and Compounds

Name	Formula	Name	Formula
neon	Ne	calcium hydroxide	$Ca(OH)_2$
sulfuric acid	H_2SO_4	magnesium nitrate	$Mg(NO_3)_2$
glucose	$C_6H_{12}O_6$	sodium chloride	$NaCl$
uranium	U	gold	Au
chlorine	Cl_2	dihydrogen oxide	H_2O
ammonia	NH_3	hydrochloric acid	HCl
methane	CH_4	sodium hydroxide	$NaOH$
iron	Fe	benzene	C_6H_6
ammonium phosphate	$(NH_4)_3PO_4$	silver nitrate	$AgNO_3$

Types of Formulas Two basic types of formulas provide different types of information about a compound. Empirical formulas include all types of compounds. Molecular formulas are important when considering compounds formed from atoms sharing electrons.

Empirical Formulas An **empirical formula** represents the simplest integer ratio in which atoms combine to form a compound. Ionic substances do not form discrete units or molecules, but rather an array of ions (charged particles). Ionic formulas indicate the ratio of the ions in a compound. The formula $MgCl_2$ tells us that for every magnesium ion in the compound there are two chloride ions. Formulas of ionic substances are empirical formulas.

Memory Jogger

proton = positive charge
electron = negative charge
neutron = no charge

Molecular Formulas Covalently bonded substances form discrete units called **molecules.** In some cases, such as H_2O, the empirical formula not only represents the simplest ratio, but it also represents the actual ratio of the atoms in a molecule of water. In other cases, the **molecular formula** may be a multiple of the empirical formula. For example the molecular formula of glucose is $C_6H_{12}O_6$, which is six times the empirical formula CH_2O.

Atoms, Compounds, and Ions

It's easy to interpret a formula for an element or a compound, but it's a bit more complicated to write the formula for a compound. How do you know what elements form the compound and in what proportion? To understand how elements form compounds, an understanding of atoms and ions is essential.

Atoms and compounds are electrically neutral; that is, they do not have a net charge. Both atoms and compounds contain positively charged protons and negatively charged electrons, but there are equal numbers of positive and negative charges, producing a neutral atom or compound.

Ions, however, are not neutral and may be either positively or negatively charged. An ion that contains more protons than electrons will be positively charged, while an ion with more electrons than protons will have a negative charge. Positively charged ions attract negatively charged ions in a ratio that produces a neutral compound.

Ionic Charges

The charge of an ion is indicated by a superscript following the symbol of the ion. When the ion has a charge of either 1+ or 1−, the number *1* is omitted, and only the sign of the charge is shown. Thus the sodium ion with a charge of 1+ is written as Na^+, and chlorine with a charge of 1− is Cl^-. The symbols of all other ions show both the size and sign of the charge. An aluminum ion is written as Al^{3+}, and an oxygen ion is shown as O^{2-}.

Polyatomic Ions A **polyatomic ion** is a group of atoms covalently bonded together, possessing a charge. Selected Polyatomic Ions in the *Reference Tables for Physical Setting/Chemistry* is a list of common polyatomic ions and their charges.

On Table 2-2 you will notice that three of the formulas contain symbols enclosed in parentheses. Parentheses are used to enclose polyatomic ions when there is more than one of the ions in a unit of a compound. The subscript written after the parentheses tells the reader how many of the ions are present in the compound. The subscript refers to each of the elements in the ion. For example, $(NH_4)_3PO_4$ tells the reader that there are three NH_4^+ ions, each containing one nitrogen atom and four hydrogen atoms, for a total of three nitrogen atoms and 12 hydrogen atoms. NH_4^+ is a polyatomic ion called the ammonium ion and has a charge of 1+. The second part of the formula, PO_4^{3-}, is the formula of one phosphate ion that contains one phosphorus atom and four oxygen atoms. Like the ammonium ion, it has a charge, but it is 3−. Figure 2-2 shows formulas, names, and models of some common polyatomic ions.

Forming a Compound Compounds can form in several different ways. One way is by the attraction of oppositely charged ions. Monatomic or polyatomic ions attract each other in a ratio that produces a neutral compound. Many of the compounds listed in Table 2-2 are formed in this manner.

Coefficients

You know what information a subscript provides in a chemical formula. However, sometimes there is a number called a **coefficient** written in front of a formula. The coefficient tells how many units of the formula are present, and it applies to the entire formula. To determine the number of atoms present, consider the formula without the coefficient, and then multiply each value by the coefficient to find the total of each type of atom. For example, $2H_2O$ means that there are two molecules of water. These two molecules contain four hydrogen atoms and two oxygen atoms.

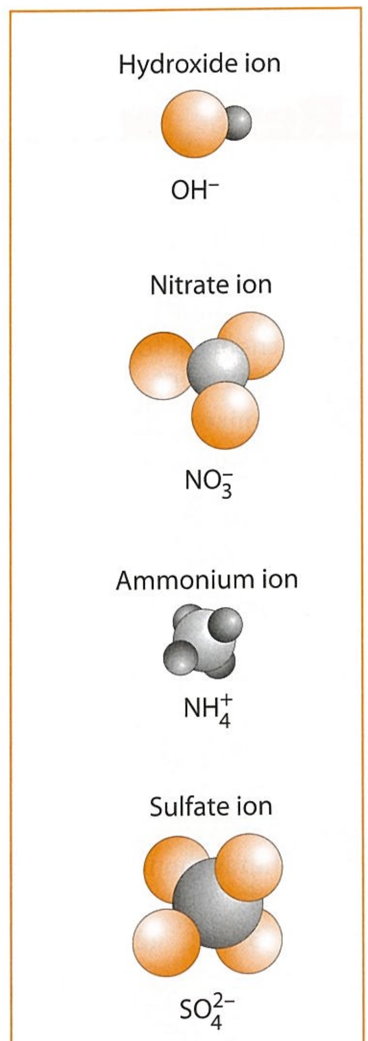


Figure 2-2. Polyatomic ions: Names, formulas, and models show the relationship of atoms in these polyatomic ions.

Table 2-3. Atoms in Calcium Nitrate	
Formula	**Atoms**
$Ca(NO_3)_2$	1 calcium
	2 nitrogen
	6 oxygen
$3Ca(NO_3)_2$	3 calcium
	6 nitrogen
	18 oxygen

The expression $4Mg(NO_3)_2$ contains four magnesium atoms, eight nitrogen atoms, and 24 oxygen atoms. Additional examples are provided in Table 2-3.

Hydrates

When water from some ionic solutions evaporates, the solute forms a crystal lattice that binds water within the structure. Such a compound is called a hydrate. These crystals have a definite number of water molecules for each unit of the compound. Barium chloride ($BaCl_2$) traps two water molecules as shown by the formula of the hydrate, $BaCl_2 \cdot 2H_2O$. Copper sulfate ($CuSO_4$) has five water molecules and a formula of $CuSO_4 \cdot 5H_2O$. Alum ($NaAl(SO_4)_2$) has 12 water molecules attached, $NaAl(SO_4)_2 \cdot 12H_2O$. The anhydrous (not hydrated) compound can be obtained by heating the crystals to drive off the water.

In a chemical reaction, the water in a hydrate does not react. However, it adds mass to the compound. For example, 10.0 g of a truly dry crystal of copper(II) sulfate contains more $CuSO_4$ than 10.0 g of the hydrated crystal, which contains both $CuSO_4$ and H_2O. If a certain amount of a material is made from a hydrated crystal, the mass of water must be considered in determining how much of the compound must be used.

Review Questions — Set 2.1

1. In a sample of solid $Ba(NO_3)_2$ the ratio of barium ions to nitrate ions is
   (1) 1:3:2 (2) 1:2 (3) 2:1 (4) 1:6
2. A chemical formula is an expression used to represent
   (1) mixtures only (2) elements only (3) compounds only (4) elements and compounds
3. Which formula represents a compound?
   (1) Ca (2) Cr (3) CO (4) Co
4. What is the total number of atoms in the formula $Ca(NO_3)_2$?
   (1) 7 (2) 2 (3) 3 (4) 9
5. What is the total number of sulfur atoms in the formula $(NH_4)_2SO_4$?
   (1) 1 (2) 2 (3) 3 (4) 4
6. What is the total number of hydrogen atoms in the formula $3Mg(C_2H_3O_2)_2$?
   (1) 3 (2) 6 (3) 12 (4) 18
7. An example of an empirical formula is
   (1) S_2H_2 (2) H_2O_2 (3) C_2Cl_2 (4) $CaCl_2$
8. Which is an empirical formula?
   (1) C_2H_2 (2) C_2H_4 (3) Al_2Cl_6 (4) K_2O
9. What is the empirical formula of a compound with the molecular formula $C_6H_{12}O_6$?
   (1) $C_4H_8O_4$ (2) $C_3H_6O_3$ (3) $C_2H_4O_2$ (4) CH_2O
10. Which compound has the same empirical and molecular formula?
    (1) H_2O_2 (2) NH_3 (3) C_2H_6 (4) Hg_2Cl_2
11. The empirical formula of a compound is CH_2. The molecular formula of this compound could be
    (1) CH_4 (2) C_2H_2 (3) C_2H_4 (4) C_3H_3

Answer each of the following using complete sentences.

12. What is the qualitative and quantitative information given by the formula $Ca_3(PO_4)_2$?
13. For each of the following formulas, write the name of each element and the number of atoms of that element that are in the formula.
    (a) K_3PO_4 (b) $Al(OH)_3$ (c) $Fe_2(SO_4)_3$
14. For each of the following formulas, write the name of each element and the number of atoms of that element that are in the formula.
    (a) $2K_3PO_4$ (b) $3Al(OH)_3$ (c) $5Fe_2(SO_4)_3$
15. What are the formulas and names of the polyatomic ions present in the compounds in question 14?

Writing Formulas and Naming Compounds

All compounds must be electrically neutral, that is, the sum of the charges must equal zero. Common oxidation states for each element are listed in the upper right hand corner of each element's box in the periodic table. For many elements, the oxidation state is equal to the charge on the ion. Elements from Group 1 have an oxidation number of +1 and always have a charge of 1+ in compounds. All Group 2 elements have 2+ charges in compounds. Group 3 elements usually have a 3+ charge.

Equalizing Charges

Compounds achieve neutrality by having an equal number of positive and negative charges. When a sodium ion (Na^+) and a chloride ion (Cl^-) combine, they will do so in a 1:1 ratio. The resulting formula will be NaCl, as such a ratio produces a neutral compound. Figure 2-3 shows the formulas of three compounds in which the charges of the ions are equal, but opposite.

Ion formula	Compound formula
$K^+ Cl^-$	KCl
$Mg^{2+} S^{2-}$	MgS
$Al^{3+} N^{3-}$	AlN

Figure 2-3. Examples of compounds with a 1:1 ion ratio: The three compounds shown are potassium chloride, magnesium sulfide, and aluminum nitride.

In the case of a combination of Mg^{2+} with Cl^-, a 1:1 ratio would not produce a neutral compound. To achieve neutrality there must be two Cl^- ions for each Mg^{2+}. The correct formula will be $MgCl_2$. When ions have unequal and opposite charges, a simple technique will produce the correct formula. Simply write the charge of one ion as the subscript of the other. Transfer the number only, not the sign. Notice that this procedure automatically balances the positive and negative charges, producing neutral formulas.

Polyatomic ions form compounds with oppositely charged ions in the same way as single ions. The formula for Na^+ combining with NO_3^- is simply $NaNO_3$. How would calcium (Ca^{2+}) combine with the nitrate ion (NO_3^-)? Because two nitrate ions are needed, enclose the nitrate ion in parentheses and write the subscript 2 after it, forming $Ca(NO_3)_2$.

Naming Compounds

Compounds are named according to the types of elements that form them. Ionic compounds, whether they are binary (contain only two elements) or contain polyatomic ions, are named by one method. Covalent compounds that contain only nonmetals are named by a different method.

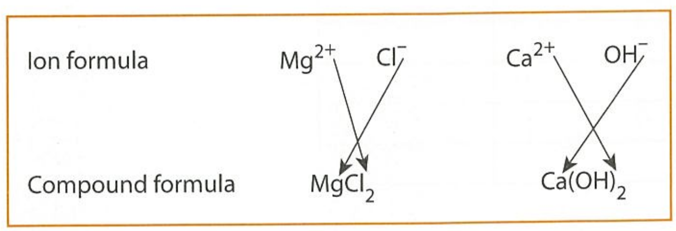


Figure 2-4. Examples of ions with unequal charges: To obtain the correct formula, write the absolute value of the ion charge as the subscript of the other ion.

Binary Ionic Compounds The name of a binary ionic compound comes from the names of the elements in the compound. The positively charged particle, often a metallic ion, is placed first. The negatively charged ion will end the formula. A compound containing the sodium ion and the ion of chlorine will begin as *sodium*. The name of the negative ion is slightly changed from the element to end in *-ide*, making the negative ion of chlorine *chloride*. Hence, the compound containing the sodium and chloride ions is simply sodium chloride. Figure 2-5 summarizes naming binary compounds.

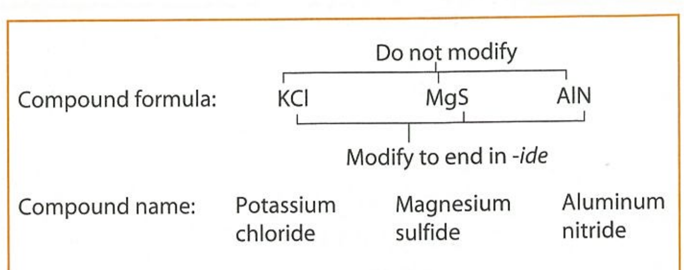


Figure 2-5. Naming binary compounds

Other Ionic Compounds Naming compounds containing polyatomic ions is simple. When the positive portion is a metal, use the unmodified metal name plus the name of the negative polyatomic ion. For example, the name of KNO_3 is potassium nitrate.

Most polyatomic ions are negatively charged. Ammonium (NH_4^+) is an important exception. In a compound containing the ammonium ion, if the negative ion is a nonmetal, the ending is *-ide*. If the ammonium ion is combined with another polyatomic ion, they each retain their names.

Examples: NH_4Cl ammonium chloride
NH_4NO_3 ammonium nitrate

Binary Covalent Compounds If a binary compound contains two nonmetals rather than a metal and a nonmetal, it is a molecular substance not composed of ions. The order in which the elements are arranged in the formula can be determined by considering the electronegativity values of the elements (See the *Reference Tables for Physical Setting/Chemistry*). The element with the lower electronegativity value is written first. For example, consider a compound containing carbon and oxygen. Because carbon has an electronegativity value of 2.6 while oxygen has a value of 3.4, carbon is written first. As in other binary compounds, the name of the compound will end in *-ide*. Because these two elements often can form more than one compound, a prefix is used to tell the reader how many atoms of each element are present. CO is named carbon monoxide, while CO_2 is named carbon dioxide. If only one atom of the first element is present, the prefix *mono-* is not used. If the element name starts with a vowel, any final *a* or *o* in the prefix is not used. For example, NO is named nitrogen monoxide, while N_2O_4 is dinitrogen tetroxide. Table 2-4 shows common prefixes used to name these compounds.

Table 2-4. Common Prefixes

Number of Atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-

The Stock System Some metals have more than one common oxidation state. For example, iron can have an oxidation number of either +2 or +3, which leads to a potential difficulty in naming compounds of iron. Which oxidation number is implied in the name iron chloride, the +2 or +3? The stock system solves this problem by simply stating the oxidation number by using Roman numerals after the name of the metal. Iron(II) chloride tells the reader that the iron has an oxidation number of +2, and the formula is $FeCl_2$. In iron(III) chloride, the iron has an oxidation number of +3, and the formula is $FeCl_3$.

Review Questions — Set 2.2

16. What is the chemical formula for zinc carbonate?
(1) Zn_2CO_3
(2) $ZnCO_3$
(3) $Zn(CO_3)_2$
(4) Zn_3CO_2

17. In a sample of solid $Al(NO_3)_3$, the ratio of aluminum ions to nitrate ions is
(1) 1:1 (2) 1:2 (3) 1:3 (4) 1:6

18. In a sample of solid calcium phosphate $Ca_3(PO_4)_2$, the ratio of calcium ions to phosphate ions is
(1) 1:1 (2) 2:3 (3) 3:2 (4) 3:4

19. What is the total number of atoms in $(NH_4)_2SO_4$?
(1) 10 (2) 11 (3) 14 (4) 15

20. What is the total number of oxygen atoms present in one unit of $Mg(ClO_3)_2$?

(1) 5 (2) 2 (3) 3 (4) 6

21. What is the total number of atoms of oxygen in the formula $Al(ClO_3)_3 \cdot 6H_2O$?

(1) 6 (2) 9 (3) 10 (4) 15

22. Write the correct formulas for the following binary ionic compounds.

(a) lithium fluoride (d) beryllium chloride
(b) calcium oxide (e) potassium iodide
(c) aluminum nitride (f) aluminum oxide

23. Write the correct formulas for the following binary molecular compounds.

(a) carbon monoxide (d) carbon dioxide
(b) boron tribromide (e) carbon tetrabromide
(c) sulfur hexafluoride (f) nitrogen dioxide

24. Write the correct formulas for the following compounds that contain polyatomic ions.

(a) sodium hydroxide (d) aluminum phosphate
(b) potassium nitrate (e) aluminum nitrate
(c) magnesium sulfate (f) ammonium nitrate

25. Name each of the following binary ionic compounds.

(a) NaBr (d) $MgCl_2$
(b) MgS (e) AlF_3
(c) CaO (f) CaI_2

26. Name each of the following binary molecular compounds.

(a) O_2F_2 (d) SF_2
(b) SiF_4 (e) H_2S
(c) S_4N_4 (f) P_4O_{10}

27. Name each of the following compounds.

(a) $Ca(NO_3)_2$ (d) Na_3PO_4
(b) KOH (e) $LiNO_3$
(c) $MgCO_3$ (f) $Mg(C_2H_3O_2)_2$

28. Write formulas for each of the following compounds.

(a) iron(II) oxide (d) mercury(II) iodide
(b) tin(II) sulfide (e) lead(II) nitrate
(c) copper(I) chloride (f) iron(III) oxide

29. Write the names of each of the following using stock nomenclature.

(a) CuCl (d) $Pb(NO_3)_2$
(b) FeS (e) $Sn(OH)_2$
(c) HgI_2 (f) Fe_2O_3

30. How many metallic elements are present in the formula $NaKSO_4$?

(1) 1 (2) 2 (3) 3 (4) 4

31. When sulfur and oxygen combine to form a compound, which element should be written first? What values are considered in making this choice?

32. A student named $KClO_3$ potassium chlorine(V) oxide. Explain to her why the use of the stock system is not correct in this case, and write the correct name of the substance.

33. Vanadium has several oxidation states. Write correct formulas for vanadium(III) oxide and vanadium(V) oxide.

34. What incorrect information is given by the formula $MgOH_2$, instead of the correct formula, $Mg(OH)_2$?

Chemical Reactions and Equations

The world around us is constantly changing. Some of these changes result from substances undergoing phase changes, such as ice melting or water boiling. In these cases, the **physical changes** that have taken place have not resulted in the formation of a new substance, but rather only a change in appearance of the starting material.

Other changes are more dramatic. When a substance is burned, whether it is a piece of paper or gasoline, the substances produced are quite different from the starting materials. These changes in which the identity of the products differs from the identity of the reactants are called **chemical changes.** In this section you will learn how to use chemical symbols to form equations that represent these chemical changes. A well-defined chemical change is called a chemical reaction.

Burning of Carbon Dioxide

carbon + oxygen $\longrightarrow$ carbon dioxide

$C(s) + O_2(g) \longrightarrow CO_2(g)$

Figure 2-6. Word equation and formulaic equation

Chemical Equations

A chemical equation shows what takes place during a chemical reaction. It is similar to an algebraic equation in that what is written on one side of the equation equals what is written on the other side. A plus sign is used to separate each of the reactants and each of the products. The arrow is read as "produces" or "yields."

A substance that enters into a reaction is called a **reactant** and is written to the left of the arrow. A substance that is produced by a reaction is called a **product** and is written to the right of the arrow.

In the equation shown in Figure 2-6, carbon and oxygen are reactants, and carbon dioxide is a product. Plus signs separate reactants and products. Notice that in the equation, the atoms of the reactants and products are the same, but the manner in which they are combined is different. This figure shows how using models of the reactants and products can be used in an equation.

Endothermic and Exothermic Processes

Chemical and physical changes involve the loss or gain of energy, most often expressed as heat. It takes heat to cook an egg. Heat is released when fuel is burned. Photosynthesis requires the energy of the sun in order to occur. When sodium hydroxide dissolves in water, the water warms up. Based on whether energy is absorbed or released, you can classify these energy changes into the two major groups as shown in Table 2-5. Because of this classification, energy is often included as either a reactant or a product in an equation.

Table 2-5. Summary of Endothermic and Exothermic Reactions

Type of Reaction	Surrounding Temperature	Potential Energy of Reactants	Potential Energy of Products	Energy Change
Endothermic	decreases	less	more	positive
Exothermic	increases	more	less	negative

Endothermic Processes Processes that require energy in order to occur are called **endothermic** processes. The physical change of ice melting is endothermic. Chemical changes that occur as food cooks are endothermic. The energy required is absorbed from the surroundings, thus lowering the surrounding temperature. In endothermic processes, the reactants absorb energy as they become products. Hence, the products have more potential energy than the reactants.

$$H_2O(s) + \text{energy} \rightarrow H_2O(\ell)$$

$$6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Exothermic Processes Processes that release thermal energy when they occur are **exothermic**. The burning of carbon in oxygen is an example of an exothermic reaction. Freezing of water is exothermic. The energy released from these processes is given off to the surroundings, thus raising the surrounding temperature. In exothermic reactions, the products have less potential energy than the reactants.

$$CH_4 + 3O_2 \rightarrow CO_2 + 2H_2O + \text{energy}$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Balancing Chemical Equations

You can see by examining a correctly written chemical equation that the number of each type of atom is the same on both sides of the equation. This observation confirms the law of conservation of mass, which states that matter is neither created nor destroyed in chemical reactions. In any chemical reaction, the numbers and kinds of atoms must remain unchanged in the reaction.

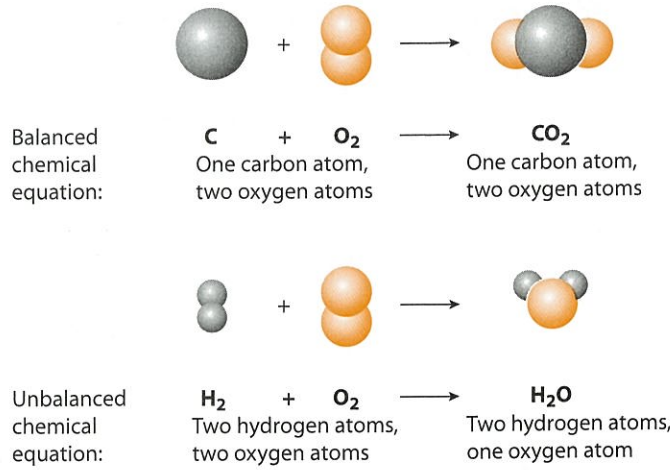


Figure 2-7. **A balanced and an unbalanced equation**

Look at Figure 2-7. In the first equation there is conservation of atoms. There is one carbon atom shown on both the reactant and product side and two atoms of oxygen on either side. This equation agrees with the law of conservation of mass and is called a balanced equation.

The second equation is different. While there are two atoms of hydrogen on both sides of the arrow, there are two atoms of oxygen on the reactant side but only one atom of oxygen on the product side. This equation is not balanced. As it is written, one atom of oxygen has been lost, or not conserved.

The equation must be changed so that it is balanced. How is this done? Remember that subscripts show the ratio of different types of atoms, and subscripts cannot be changed in a correctly written formula. The formula of oxygen gas is O_2 and cannot be changed. The only way to balance an equation, once correct formulas have been written, is to change the coefficients in the equation. Remember that coefficients are the numbers written before a formula.

You may want to think of balancing an equation as being similar to balancing a seesaw. In the second example the unbalanced equation is heavy with oxygen atoms on the reactant side. Because none of the reactant oxygen atoms can be removed, the only way to correct the imbalance is to add more oxygen atoms to the product side. This is done by placing a coefficient of 2 in front of the formula of water.

$$H_2(g) + O_2(g) \rightarrow \mathbf{2}H_2O(g)$$

The coefficient applies to both the hydrogen and oxygen in water. The equation is now balanced in terms of oxygen atoms, as there are two on each side. The hydrogen atoms are now unbalanced because there are four hydrogen atoms on the product side but only two on the reactant side. This can be remedied by placing a 2 in front of the formula of hydrogen.

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

Inspection of the equation shows that there now is a conservation of atoms. Four atoms of hydrogen and two atoms of oxygen are now on each side of the equation. The equation is now balanced.

If you examine equations that involve polyatomic ions, you will notice that sometimes the ions are the same in the reactants and products, and sometimes they are not. If polyatomic ions remain the same, they can be balanced as a unit. For example, in the following unbalanced equation, the nitrate ion can be balanced as a unit because it stays a nitrate ion on the product side of the equation.

$$AgNO_3 + MgCl_2 \rightarrow Mg(NO_3)_2 + AgCl$$

However, in the following unbalanced equation, the phosphite (PO_3^{3-}) and nitrate ions are changed during the reaction. They do not appear unchanged on the product side of the equation. In such a case, each type of atom must be balanced separately, and the polyatomic ions cannot be balanced as a unit.

$$HNO_3 + H_3PO_3 \rightarrow NO + H_3PO_4 + H_2O$$

You may have noticed that some symbols have appeared in parentheses after the formulas. It is often important to indicate the physical state of the substances in an equation. The symbol (*s*) is used to show that the substance is a solid, (ℓ) indicates that it is a liquid, and (*g*) shows the substance to be a gas. In addition, (*aq*) means that the material is dissolved in water; that is, it is in an aqueous solution. Table 2-6 summarizes some common symbols used in equations.

Table 2-6. Common Notation Used in Equations

Symbol	Meaning
+	Separates two reactants or two products
→	Separates reactants from products; read as *yields* or *produces*
(*s*)	Identifies the substance as a solid
(ℓ)	Identifies the substance as a liquid
(*g*)	Identifies the substance as a gas
(*aq*)	Identifies the substance as being dissolved in aqueous (water) solution

Review Questions — Set 2.3

35. Consider the following unbalanced equation.

$$C_3H_8(g) + O_2(g) \rightarrow H_2O(g) + CO_2(g)$$

When the equation is completely balanced using smallest whole numbers, the coefficient of O_2 is

(1) 5 (2) 2 (3) 3 (4) 7

36. When the equation $Al(s) + O_2(g) \rightarrow Al_2O_3(s)$ is correctly balanced using smallest whole numbers, the sum of the coefficients will be

(1) 9 (2) 7 (3) 3 (4) 12

37. Consider the following unbalanced equation.

$$Ca(OH)_2 + (NH_4)_2SO_4 \rightarrow CaSO_4 + NH_3 + H_2O$$

What is the sum of the coefficients when the equation is completely balanced using the smallest whole-number coefficients?

(1) 5 (2) 7 (3) 9 (4) 11

38. When the equation $Al_2(SO_4)_3 + ZnCl_2 \rightarrow AlCl_3 + ZnSO_4$ is correctly balanced using smallest whole numbers, the sum of the coefficients is

(1) 9 (2) 8 (3) 5 (4) 4

39. Consider the following unbalanced equation.

$$C_8H_{16}(g) + O_2(g) \rightarrow H_2O(g) + CO_2(g)$$

When the equation is completely balanced using smallest whole numbers, the coefficient of O_2 is

(1) 8 (2) 12 (3) 14 (4) 16

40. Consider the following unbalanced equation.

$$FeCl_2 + Na_2CO_3 \rightarrow FeCO_3 + NaCl$$

When the equation is completely balanced using smallest whole numbers, the coefficient of NaCl is

(1) 6 (2) 2 (3) 3 (4) 4

41. Consider the following unbalanced equation.

$$Ag + H_2S \rightarrow Ag_2S + H_2$$

What is the sum of the coefficients when the equation is completely balanced using the smallest whole-number coefficients?

(1) 5 (2) 8 (3) 10 (4) 4

42. Consider the following incomplete equation:

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

Which expression completes the balanced equation?

(1) $Na_2O(aq)$
(2) $2Na_2O(aq)$
(3) $NaOH(aq)$
(4) $2NaOH(aq)$

43. Consider the following unbalanced equation.

$$N_2(g) + O_2(g) \rightarrow N_2O_5(g)$$

When the equation is completely balanced using smallest whole numbers, the coefficient of $N_2(g)$ is

(1) 1 (2) 2 (3) 5 (4) 4

Types of Reactions

While it would be difficult, if not impossible, to put all chemical reactions into distinct categories, there are four major types of reactions that you should know. It is important to be able to recognize these types and write equations to represent them.

Synthesis (Combination) Reactions When two or more reactants combine to form a single product, the reaction is a **synthesis,** or combination, reaction. The combination of hydrogen and oxygen to form water that was shown earlier is an example.

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

Many synthesis reactions are commonplace, such as the rusting of iron.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

Synthesis reactions not only take place between elements, but they may also involve compounds.

$$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$$

It is convenient to write this type of equation in a general form such as

$$A + B \rightarrow AB$$

A and B represent either elements or compounds, and AB represents a compound that is made of A and B. See Figure 2-8.

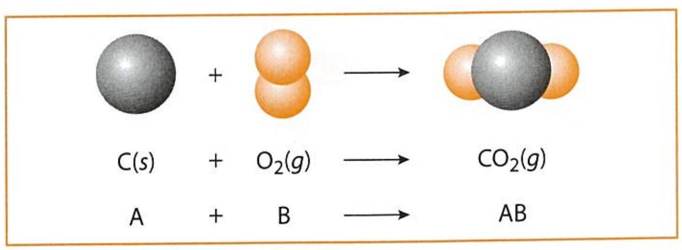


Figure 2-8. Equation of a synthesis reaction: In this example, two elements combine to form a compound.

Decomposition (Analysis) Reactions A **decomposition,** or **analysis,** reaction is the reverse of a synthesis reaction in that a single compound is broken down (decomposed) into two or more simpler substances. All decomposition reactions begin with a single reactant.

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

Although many decomposition reactions produce elements as the products, Figure 2-9 shows the breaking down of one compound into two compounds.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

The general form of this reaction is the exact opposite of the equation for a synthesis reaction.

$$AB \rightarrow A + B$$

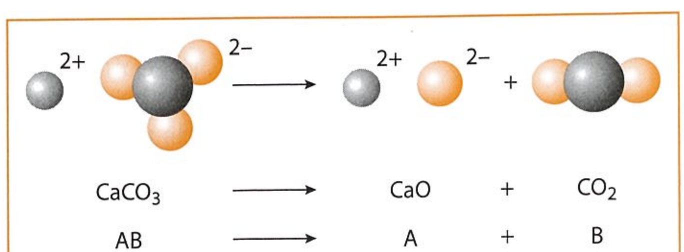
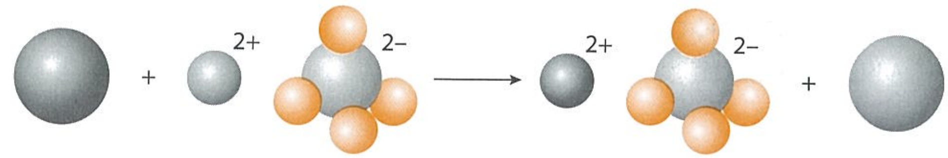


Figure 2-9. Equation of a decomposition reaction: The models for $CaCO_3$ and CaO show that the compounds are ionic and do not form molecules. They are compounds that exist as ions.



Fe + $CuSO_4\,(aq)$ ⟶ $FeSO_4\,(aq)$ + Cu

A + BX ⟶ AX + B

Figure 2-10. Equation of a single replacement reaction: **The copper and iron ions are part of the compounds that are in solution, but the iron and copper atoms are solid metals.**

Single Replacement Reactions When a piece of copper wire is placed into a solution of silver nitrate, a chemical reaction takes place. In a short period of time shiny crystals form on the copper wire, and the solution gradually becomes blue. Analysis of the crystals shows them to be silver metal. The blue color is caused by copper ions in solution. In this reaction the copper metal has replaced silver ions in silver nitrate, producing silver metal and copper ions.

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

This type of reaction where one element replaces another element in a compound is called a **single replacement** reaction (Figure 2-10). This type of reaction always involves an element and a compound. The general formula for this type of reaction where a metal replaces another metal in a compound is

$$A + BX \rightarrow B + AX$$

Will the reverse reaction take place, that is, will silver metal react with copper nitrate to produce copper and silver nitrate? If silver is placed into copper nitrate solution, no copper is formed. How can we predict whether or not a reaction will take place? The Activity Series in the *Reference Tables for Physical Setting/Chemistry* will provide the information. The table is arranged so that a metal listed on the table will react with the compound of a metal that is below it. For example, Zn is above Cu on the table. Therefore, Zn will react with a compound of copper such as $Cu(NO_3)_2$.

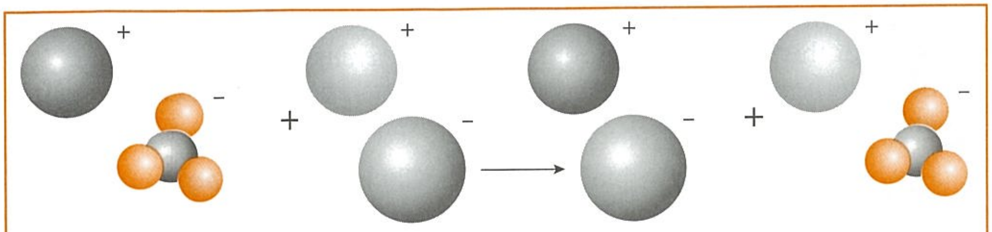
$$Zn + Cu(NO_3)_2 \rightarrow Cu + Zn(NO_3)_2$$

Because Cu is below Zn, it will not react with compounds of Zn.

$$Cu + Zn(NO_3)_2 \rightarrow \text{no reaction.}$$

It is worth noting that there is one element that is not a metal in the left column of the Activity Series, H_2. All metals above hydrogen will react with acids to release hydrogen gas and produce a salt. For example,

$$Mg + 2HCl \rightarrow H_2 + MgCl_2$$



$$AgNO_3(aq) + KCl(aq) \rightarrow AgCl(s) + KNO_3(aq)$$

$$AB + CD \rightarrow AD + CB$$

Figure 2-11. An equation for a double replacement reaction: Although all the compounds are ionic, AgCl is an ionic compound that is not soluble in water. Crystals of AgCl form a precipitate.

Silver (Ag) is below hydrogen on the table, so it will not react with acids.

In the second column of the Activity Series is a short list of nonmetals. A nonmetal will replace a less active nonmetal in a compound according to the equation

$$A + XB \rightarrow B + XA$$

Fluorine is listed as the most active nonmetal, and it will replace chlorine, bromine, and iodine from their binary compounds.

$$F_2 + 2NaCl \rightarrow Cl_2 + 2NaF$$

Because chlorine is below fluorine on the list, it will not replace fluorine in a compound.

$$Cl_2 + NaF \rightarrow \text{no reaction}$$

When given a possible reaction between an element and an ionic compound, consult the Activity Series to determine whether or not a reaction will occur.

Double Replacement Reactions **Double replacement** reactions generally involve two soluble ionic compounds that react in solution to produce a precipitate, a gas, or a molecular compound such as water. Figure 2-11 shows that when aqueous solutions of silver nitrate and sodium chloride are mixed, a white precipitate of silver chloride is produced according to the following equation.

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

Double replacement equations can be represented by the general equation

$$AB + CD \rightarrow AD + CB$$

Just as not all combinations of single replacement reactants will produce a reaction, the same is true for double replacement reactions.

How can you determine if two ionic compounds will react? There are three situations that might cause a double replacement to occur.

1. A reaction will occur if one of the products is a solid (precipitate). Consult the Solubility Guidelines in the *Reference Tables for Physical Setting/Chemistry*. Check the solubility of the two ionic products. For example, in

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

silver chloride is listed as insoluble, and sodium nitrate is listed as soluble. Because one of the products is insoluble, the reaction will occur, and a precipitate will be observed.

2. A reaction will occur if one of the products is a gas. For example,

$$Na_2S(aq) + 2HCl(aq) \rightarrow H_2S(g) + 2NaCl(aq)$$

3. A reaction will occur if a molecular substance such as water is formed. For example,

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

Review Questions — Set 2.4

Write and balance equations for the following synthesis reactions.

44. hydrogen and bromine forming hydrogen bromide

45. fluorine and argon forming argon trifluoride

46. sulfur and oxygen forming sulfur dioxide

47. calcium and chlorine forming calcium chloride

48. nickel and oxygen forming nickel(II) oxide

Write and balance equations for the following decomposition reactions.

49. decomposition of water into hydrogen and oxygen

50. decomposition of aluminum oxide into aluminum and oxygen

51. decomposition of sodium chloride into sodium and chlorine

52. decomposition of ammonia into hydrogen and nitrogen

53. decomposition of mercury(II) oxide into mercury and oxygen

For each of the following, indicate whether or not a single replacement reaction will occur.

54. aluminum and hydrochloric acid

55. silver and magnesium chloride

56. chromium and lead(II) nitrate

57. silver and gold(III) chloride

58. chlorine and sodium iodide

59. Identify each of the following as equations for a synthesis (*S*), decomposition (*D*), single replacement (*SR*), or double replacement (*DR*) reactions.

(a) $Zn + HCl \rightarrow ZnCl_2 + H_2$
(b) $NaClO_3 \rightarrow NaCl + O_2$
(c) $P_4 + Cl_2 \rightarrow PCl_3$
(d) $HCl + Mg(OH)_2 \rightarrow MgCl_2 + H_2O$
(e) $BaO + SO_3 \rightarrow BaSO_4$
(f) $Pb + AgNO_3 \rightarrow Ag + Pb(NO_3)_2$
(g) $AgNO_3 + Na_2CrO_4 \rightarrow Ag_2CrO_4 + NaNO_3$
(h) $Al + Fe_3O_4 \rightarrow Al_2O_3 + Fe$
(i) $HNO_3 + Mg(OH)_2 \rightarrow Mg(NO_3)_2 + H_2O$
(j) $Ba(NO_3)_2 + Na_2SO_4 \rightarrow BaSO_4 + NaNO_3$

For the following, write a balanced chemical equation to show how the ions would combine in a double replacement equation.

60. sodium bromide and silver nitrate form sodium nitrate and silver bromide

61. potassium carbonate and calcium nitrate form potassium nitrate and calcium carbonate

62. ammonium sulfate and barium chloride form ammonium chloride and barium sulfate

63. barium nitrate and potassium chromate form barium chromate and potassium nitrate

64. sodium hydroxide and calcium chloride form sodium chloride and calcium hydroxide

Unknown Reactants and Products

The law of conservation of mass requires that chemical reactions neither create nor destroy matter. When given a balanced equation in which either a reactant or a product is missing, you should be able to determine the formula of the missing substance. To do so, count the atoms in the formulas on both sides of the arrow. Subtract the atoms on the side with the missing formula from the side with the known substances. Any missing element must be present in the unknown.

As an example, look at the following equation.

$$2Na + 2H_2O \rightarrow X + 2NaOH$$

The reactant side is complete and contains two sodium atoms, four hydrogen atoms, and two oxygen atoms. One product is missing from the right side of the equation. There are two hydrogen atoms, two oxygen atoms, and two sodium atoms present in the other product. For the equation to balance, the missing substance must contain only two hydrogen atoms. What is the formula of a substance that contains two hydrogen atoms? H_2, hydrogen gas.

Determining Missing Mass in Equations

Just as the formula of a missing reactant or product can be determined, the mass of a missing substance can also be found. The law of conservation of mass again is the guiding principle. Matter can be neither created nor destroyed in a chemical reaction. The total mass of the reactants must equal the total mass of the products.

SAMPLE PROBLEM

If 103.0 g of potassium chlorate are decomposed to form 62.7 g of potassium chloride and oxygen gas according to the equation $2KClO_3 \rightarrow 2KCl + 3O_2$, how many grams of oxygen are formed?

SOLUTION: Identify the known and unknown values.

Known
mass of $KClO_3$ = 103.0 g
mass of KCl = 62.7 g

Unknown
mass of O_2 = ? g

Find the total mass of the reactants. $KClO_3$ is the only reactant; it has a mass of 103.0 g.

The total mass of the reactants and products must be equal.

$$\text{mass of } KClO_3 = \text{mass of } KCl + \text{mass of } O_2$$
$$103.0\text{ g} = 62.7\text{ g} + \text{mass of } O_2$$
$$\text{mass of } O_2 = 103.0\text{ g} - 62.7\text{ g}$$
$$\text{mass of } O_2 = 40.3\text{ g}$$

Review Questions

65. Identify the missing reactant or product in each of the following equations. Include any coefficient needed to balance the equation.
   (a) $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + \_\_\_\_$
   (b) $BaCl_2 + K_2CO_3 \rightarrow \_\_\_\_ + BaCO_3$
   (c) $2C_6H_6 + \_\_\_\_ \rightarrow 12CO_2 + 6H_2O$
   (d) $CaCO_3 \rightarrow CaO + \_\_\_\_$

66. Identify the missing reactant or product in each of the following equations. Include any coefficient needed to balance the equation.
   (a) $2Al + \_\_\_\_ \rightarrow 2AlCl_3 + 3H_2$
   (b) $\_\_\_\_ + H_2O \rightarrow H_2CO_3$
   (c) $2NaOH + \_\_\_\_ \rightarrow NaOCl + NaCl + H_2O$
   (d) $Cr_2O_3 + 2Al \rightarrow \_\_\_\_ + 2Cr$

67. Identify the missing reactant or product in each of the following equations. Include any coefficient needed to balance the equation.
   (a) $2HNO_3 + \_\_\_\_ \rightarrow Mg(NO_3)_2 + 2H_2O$
   (b) $2NH_4NO_3 \rightarrow \_\_\_\_ + 4H_2O + O_2$
   (c) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + \_\_\_\_$
   (d) $3PbO + \_\_\_\_ \rightarrow 3Pb + N_2 + 3H_2O$

68. Identify the missing reactant or product in each of the following equations. Include any coefficient needed to balance the equation.
   (a) $3Cu + 8\ HNO_3 \rightarrow 3Cu(NO_3)_2 + 4H_2O + \_\_\_\_$
   (b) $C_6H_{11}OH \rightarrow C_6H_{10} + \_\_\_\_$
   (c) $4NH_3 + 5O_2 \rightarrow \_\_\_\_ + 6H_2O$
   (d) $Ca(OH)_2 + \_\_\_\_ \rightarrow CaCl_2 + 2H_2O$

69. Identify the missing reactant or product in each of the following equations. Include any coefficient needed to balance the equation.
   (a) $2AgNO_3 + \_\_\_\_ \rightarrow Ag_2S + 2NaNO_3$
   (b) $H_2C_2O_4 + 2NaOH \rightarrow \_\_\_\_ + 2H_2O$
   (c) $CCl_4 + 2HF \rightarrow CCl_2F_2 + \_\_\_\_$
   (d) $\_\_\_\_ + CO_2 \rightarrow K_2CO_3$

70. What mass of carbon dioxide will be produced if 144 g of carbon react with 384 g of oxygen gas according to the equation $C + O_2 \rightarrow CO_2$?

71. How many grams of HCl are produced when 16.0 g of CH_4 react with 71.0 g of Cl_2 to produce 50.5 g of CH_3Cl and HCl according to the equation $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$?

72. Consider the following equation.

$$3C_2H_4O_2 + PCl_3 \rightarrow 3C_2H_3OCl + H_3PO_3$$

   How many grams of products will be produced if 90 g of $C_2H_4O_2$ completely react with 68 g of PCl_3?

73. How many grams of silver nitrate are needed to react with 156.2 g of sodium sulfide to produce 595.8 g of silver sulfide and 340.0 g of sodium nitrate?

$$2AgNO_3 + Na_2S \rightarrow Ag_2S + 2NaNO_3$$

74. Given the equation $PbO_2 \rightarrow PbO + O_2$, how many grams of oxygen will be produced if 47.8 g of lead(IV) oxide decompose to form 44.6 g of lead(II) oxide and oxygen gas?

75. Consider the following equation.

$$2Al + 3CuSO_4 \rightarrow Al_2(SO_4)_3 + 3Cu$$

   Copper metal is produced when aluminum metal is reacted with copper(II) sulfate. How many grams of copper metal will be produced if 10.8 g of aluminum react with 95.8 g of copper sulfate to produce copper metal and 68.5 g of aluminum sulfate?

76. How many grams of Fe are needed to react with 8.0 g of O_2 to produce 28.9 g of Fe_3O_4 according to the equation $3Fe + 2O_2 \rightarrow Fe_3O_4$?

77. How many metric tons of nitric acid are produced from the reaction of 10.8 metric tons of N_2O_5 reacting with 1.8 metric tons of water according to the equation $N_2O_5 + H_2O \rightarrow 2HNO_3$?

78. How many pounds of sulfur will be produced from the decomposition of 318.2 pounds of copper(I) sulfide to produce 254.0 pounds of copper metal and sulfur according to the equation $Cu_2S \rightarrow 2Cu + S$?

79. Given the equation $2HgO \rightarrow 2Hg + O_2$, how many grams of mercury(II) oxide are needed to produce 12.7 g of mercury and 3.2 g of oxygen?

Practice Questions for the New York Regents Exam

Directions
Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 What is the chemical formula of iron(III) sulfide?
(1) $Fe_2(SO_3)_3$ (3) $FeSO_3$
(2) Fe_2S_3 (4) FeS

2 Two molecules of hydrogen are represented by
(1) H_2 (2) $2H_2$ (3) $2H^+$ (4) $2H$

3 Which of the following is a polyatomic ion?
(1) CH_3COOH (3) Na^+
(2) $Cr_2O_7^{2-}$ (4) H_2

4 Pure oxygen reacts with metals to form
(1) oxalates (3) oxides
(2) oxalites (4) oxygenates

5 Which of the following is the formula of a compound?
(1) Fr (3) LiH
(2) Mn (4) O_3

6 A chemical formula represents
(1) qualitative information only
(2) quantitative information only
(3) both quantitative and qualitative information
(4) neither qualitative nor quantitative information

7 An empirical formula represents
(1) qualitative information only
(2) only the metallic elements in the compound
(3) the lowest integer ratio of the elements in a compound
(4) a multiple of the simplest ratio of the elements in a compound

8 In an endothermic reaction
(1) energy is a product and the surrounding temperature decreases
(2) energy is a product and the surrounding temperature increases
(3) energy is a reactant and the surrounding temperature increases
(4) energy is a reactant and the surrounding temperature decreases

9 A reaction in which two substances combine to form a single product is called a
(1) decomposition
(2) synthesis
(3) single replacement
(4) double replacement

10 As an exothermic reaction occurs, the surrounding temperature
(1) decreases
(2) increases
(3) remains the same
(4) depends on the reaction

Part B–1

11 What is the total number of atoms of oxygen in the formula $Mg(ClO_4)_2 \cdot 6H_2O$?
(1) 6 (2) 8 (3) 10 (4) 14

12 Which formula is correctly paired with its name?
(1) $MgCl_2$, magnesium chlorine
(2) K_2O, diphosphorus oxide
(3) $CuCl_2$, copper(II) chloride
(4) FeO, iron(III) oxide

13 What is the IUPAC name for the compound ZnO?
(1) zinc oxalate (3) zinc hydroxide
(2) zinc peroxide (4) zinc oxide

14 Given the balanced equation representing a reaction

$$2H_2 + O_2 \rightarrow 2H_2O$$

What is the mass of H_2O produced when 10.0 grams of H_2 reacts completely with 80.0 grams of O_2?
(1) 800. g (2) 180. g (3) 70.0 g (4) 90.0 g

15 What is the correct formula of nickel(II) oxide?
(1) NiO (3) NiO_2
(2) Ni_2O (4) Ni_2O_2

16 What is the name of the compound whose formula is N_2O_5?
(1) nitrogen oxide
(2) dinitrogen pentoxide
(3) pentanitrogen dioxide
(4) dinitrogen oxide

17 Which is the correct formula of dichlorine monoxide?
(1) ClO (2) Cl_2O (3) ClO_2 (4) OCl

18 Which of the following is a synthesis reaction?
(1) $Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$
(2) $2Cu + O_2 \rightarrow 2CuO$
(3) $CuCO_3 \rightarrow CuO + CO_2$
(4) $CuO + H_2 \rightarrow Cu + H_2O$

19 Which of the following reactions will *not* take place spontaneously?
(1) $Ca + AgNO_3$
(2) $Pb + Al(NO_3)_3$
(3) $Cr + Pb(NO_3)_2$
(4) $Co + HCl$

20 Consider the following unbalanced equation.

$Mg_2Si + HCl \rightarrow MgCl_2 + SiH_4$

When the equation is balanced using the smallest whole-number coefficients, the coefficient of HCl is
(1) 1 (2) 2 (3) 3 (4) 4

21 Consider the following unbalanced equation.

$Fe + H_2O \rightarrow Fe_3O_4 + H_2$

When correctly balanced using smallest whole numbers, the sum of the coefficients is
(1) 4 (2) 7 (3) 11 (4) 12

Parts B–2 and C

Base your answers to questions 22 and 23 on the information below.

In an experiment, 2.54 grams of copper completely reacts with sulfur, producing 3.18 grams of copper(I) sulfide.

22 Determine the total mass of the sulfur consumed.

23 Write the chemical formula of the compound produced.

Base your answers to questions 24 through 26 on the information below.

A tablet of one antacid contains citric acid, $H_3C_6H_5O_7$, and sodium hydrogen carbonate, $NaHCO_3$. When the tablet dissolves in water, bubbles of CO_2 are produced. This reaction is represented by the incomplete equation below.

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow$$
$$Na_3C_6H_5O_7(aq) + 3CO_2(g) + 3 \_\_\_\_ (l)$$

24 Complete the equation by writing the missing chemical formula.

25 State evidence that a chemical reaction occurred when the tablet was placed in the water.

26 Determine the total number of oxygen atoms in the reactants of the balanced equation.

Use the following information to answer questions 27 and 28.

In an investigation, a dripless wax candle is massed and then lighted. As the candle burns, a small amount of liquid wax forms near the flame. After 10 minutes, the candle's flame is extinguished and the candle is allowed to cool. The cooled candle is massed.

27 Identify one physical change that takes place in this investigation.

28 State one observation that indicates that a chemical change has taken place.

---

29 Balance this equation using the lowest whole-number coefficients.

$$\_\_\_\_ C_6H_{12}O_6 \rightarrow \_\_\_\_ C_2H_5OH + \_\_\_\_ CO_2$$

30 Identify the type of reaction represented in the equation in question 29.

Use the following information to answer questions 31 and 32.

Magnesium metal reacts with hydrochloric acid to produce hydrogen. Balance the equation for the reaction using the lowest whole-number integers.

31 $\_\_\_\_ Mg(s) + \_\_\_\_ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

32 What type of chemical reaction occurs during this reaction?

Use the following information to answer questions 33 and 34.

Rust contains Fe_2O_3. Given the balanced equation representing the formation of rust:

$$\_\_\_\_ Fe(s) + \_\_\_\_ O_2(g) \rightarrow \_\_\_\_ Fe_2O_3(s).$$

33 Balance the equation using the smallest whole-number coefficients.

34 Identify the type of reaction represented by this equation.