CONCEPT 4

A chemical equation represents what happens to the atoms in a reaction.

Activity

Paper Clip Equation

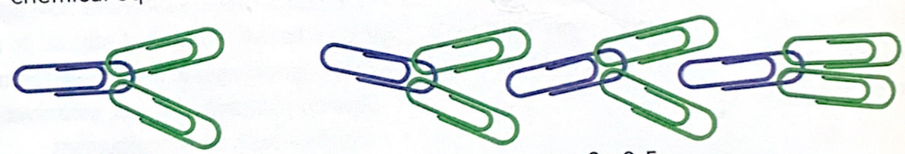
A chemical reaction is represented below. The compounds to the left of the arrow represent substances that react and undergo a change. The compounds to the right of the arrow are the new substances that form.

$$Na_3P + CaF_2 \longrightarrow Ca_3P_2 + NaF$$

How many atoms of each element are on the left-hand side of the equation? How many atoms of each element are on the right-hand side of the arrow?

Does this chemical equation reflect the conservation of mass? Explain.

Use paper clips to model this reaction. One paper clip of a given colour should represent one atom of a given element. Work with the paper clip models to represent a reaction that has the same number of each colour of paper clip in the reacting substances as the substances formed. How could you change the chemical equation to reflect your models?



CaF_2 $3 \times CaF_2$

chemical equation the representation of a chemical reaction using words or chemical formulas

reactant a substance that undergoes a chemical change

product a substance formed in a chemical change

A **chemical equation** is a statement that uses words or symbols to describe a chemical reaction. Figure 2.12 shows how information is represented in a chemical equation. A **reactant** is any substance that undergoes a chemical change in the reaction. A **product** is any new substance that is formed from the reaction. An arrow is used to point towards the end result, which is product formation.

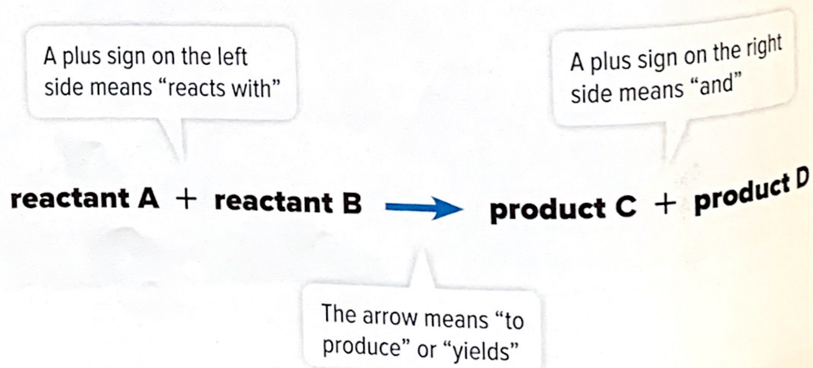


Figure 2.12 Reactants undergo chemical change to form products.

Using Chemical Equations

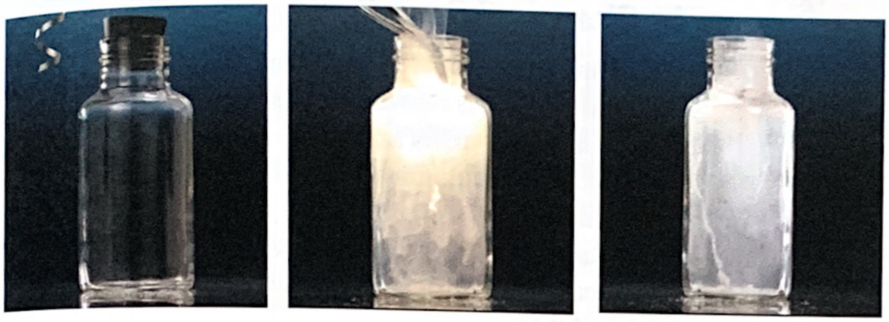


Figure 2.13 Magnesium and oxygen react to produce magnesium oxide. **Analyzing: Is there an overall release or absorption of energy in this reaction? What evidence supports this?**

Figure 2.13 shows the chemical reaction between magnesium metal and oxygen gas, which produces magnesium oxide. One way to represent this reaction is with a word equation:

magnesium + oxygen ⟶ magnesium oxide

A *word equation* uses words to describe what happens to reactants and products in a chemical reaction. However, the information it provides is limited.

Skeleton Equation (Unbalanced chemical equation)

A *skeleton equation* provides the chemical formulas for the reactants and products. However, it does not necessarily reflect the law of conservation of mass. The correct proportions of reactants and products may not be shown. In the example below, there are different numbers of atoms of oxygen on each side of the equation.

$$Mg + O_2 \longrightarrow MgO$$

Balanced Chemical Equation

According to the law of conservation of mass, atoms are never destroyed or created in a chemical reaction—they are just rearranged. So, in a *balanced chemical equation*, the same number of atoms of each element must appear on both sides of the arrow. This is achieved using **coefficients**.

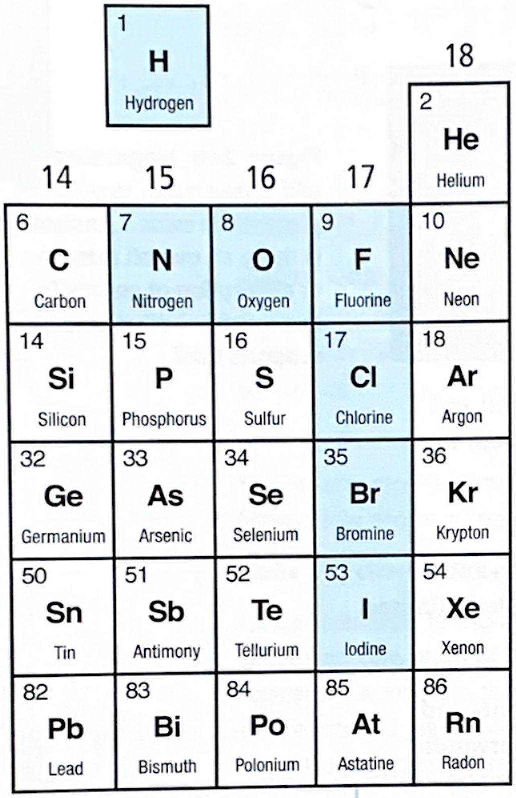
coefficient number placed in front of a chemical formula in a balanced chemical equation to show the ratios of substances in a reaction

Balanced chemical equations are always written using the smallest whole number ratio of coefficients. The example below tells you that two atoms of magnesium combine with one molecule of oxygen to produce two formula units of magnesium oxide. A chemical equation may also provide information about the physical states of the reactants and products.

A substance can be a gas (g), liquid (ℓ), or solid (s). Substances that are dissolved in water are aqueous solutions (aq).

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

The number placed in front of a chemical formula is called a coefficient. The coefficient applies to the whole formula that it is placed in front of. Coefficients not shown are assumed to be 1.



Diatomic and Polyatomic Elements in Chemical Equations

Notice in the chemical equation on the previous page that oxygen is represented as $O_2(g)$. Recall that oxygen naturally exists as a diatomic ("two-atom") element. Other diatomic elements are hydrogen, $H_2(g)$, nitrogen, $N_2(g)$, fluorine, $F_2(g)$, chlorine, $Cl_2(g)$, bromine, $Br_2(\ell)$, and iodine, $I_2(s)$. Sulfur and phosphorus exist as the polyatomic elements $S_8(s)$ and $P_4(s)$.

A common way to remember the diatomic elements is to "visualize" them on the periodic table forming the number "7," with the exception of hydrogen (**Figure 2.14**).

Figure 2.14 Except for hydrogen, diatomic elements are positioned in the periodic table in the shape of a "7." **Innovating: Develop an abbreviation or other memory aid to help you remember the diatomic and polyatomic elements.**

Coefficients versus Subscripts

It is important to be clear about how subscripts in chemical formulas differ from coefficients in chemical equations. As shown in **Figure 2.15**, the subscripts in a chemical formula indicate how many atoms of each element are present in a molecule or formula unit. The coefficient indicates how many molecules or formula units are present.

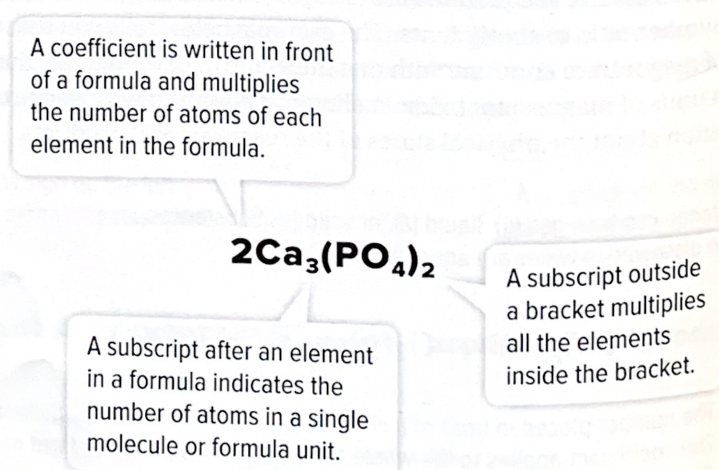


Figure 2.15 Coefficients indicate the number of molecules or formula units. **Analyzing: How many atoms of each element are represented?**

Balancing Chemical Equations

Balancing chemical equations involves applying the law of conservation of mass. The number of atoms of each element on the reactant side of the equation must equal the number of atoms of the same elements on the product side of the equation. Remember that equations are balanced using coefficients, never by changing the subscripts in chemical formulas. Changing a subscript in a chemical formula changes the identity of the compound.

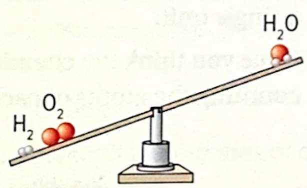
How to Balance a Chemical Equation

1. $H_2(g) + O_2(g) \longrightarrow H_2O(\ell)$

   In the skeleton equation, there is the same number of hydrogen atoms on both sides of the equation. There are more oxygen atoms in the reactants, however, than in the product.

Checking the Atom Balance

Element	Reactant	Product	Equal?
H	2	2	yes
O	2	1	no

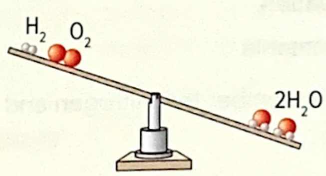


2. $H_2(g) + O_2(g) \longrightarrow 2H_2O(\ell)$

   Balance equations by adjusting coefficients. Placing the coefficient 2 in front of $H_2O(\ell)$ balances the oxygen atoms on each side of the equation. But now there are 4 hydrogen atoms on the product side and only 2 on the reactant side.

Checking the Atom Balance

Element	Reactant	Product	Equal?
H	2	4	no
O	2	2	yes

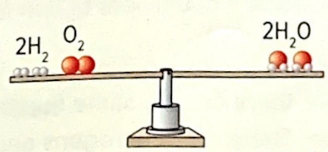


3. $2H_2(g) + O_2(g) \longrightarrow 2H_2O(\ell)$

   Placing the coefficient 2 in front of $H_2(g)$ brings the total number of hydrogen atoms to 4 on each side of the equation. The equation is now balanced. Once you think the chemical equation is balanced, do a final check by counting the atoms of each element one more time.

Checking the Atom Balance

Element	Reactant	Product	Equal?
H	4	4	yes
O	2	2	yes



Tips for Balancing Chemical Equations

When balancing a chemical equation, it is important to remember that each equation is different and the identical approach does not work for every equation. However, there are some general guidelines you can follow.

- Begin by checking that all chemical formulas are correct so that you do not waste time trying to balance an equation that is not possible.
- Balance compounds first and elements last.
- When you have placed a coefficient for a compound, balance the rest of the atoms in that compound before moving on to the next substance.
- Balance atoms that appear only once on the reactant side and product side first. Elements such as hydrogen and oxygen often appear in more than one reactant or more than one product, so it is easier to balance them after the other elements are balanced.
- If a polyatomic ion appears in both a reactant and a product, treat it as a single unit.
- Once you think the chemical equation is balanced, do a final check by counting the atoms of each element on both sides of the equation.

Sample Problem 1:

Writing a Balanced Chemical Equation

In the industrial production of gaseous ammonia, gaseous nitrogen and gaseous hydrogen are the reactants. Write the balanced chemical equation for this reaction, including the states of reactants and products.

Solution

1. Begin by writing a word equation.

   nitrogen + hydrogen ⟶ ammonia

2. Write a skeleton equation. Remember that nitrogen and hydrogen are diatomic elements. Include the states.

   $N_2(g) + H_2(g) \longrightarrow NH_3(g)$

3. Use coefficients to balance the equation. First consider the compound in the equation. You need to have 2 nitrogen atoms in the product to balance the nitrogen in the reactants. Therefore, place a coefficient of 2 in front of $NH_3(g)$.

   $N_2(g) + H_2(g) \longrightarrow 2NH_3(g)$

Now the nitrogen atoms are balanced. The hydrogen atoms are not balanced, because there are 2 hydrogen atoms on the reactant side and 6 hydrogen atoms on the product side. Therefore, place a coefficient of 3 in front of $H_2(g)$.

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

4. Do a final check to make sure there are the same number of atoms of each element on both sides of the equation. There are 2 nitrogens and 6 hydrogens on both sides.

Sample Problem 2:

Writing a Balanced Chemical Equation Containing a Polyatomic Ion

Balance the following skeleton equation.

$CaCl_2(aq) + AgNO_3(aq) \longrightarrow AgCl(s) + Ca(NO_3)_2(aq)$

Solution

1. Write out the equation. Make sure that you have copied each chemical formula correctly.
2. Use coefficients to balance the equation. When a polyatomic ion appears in both a reactant and a product, treat it as a single unit. There is one NO_3^- in the reactants and two NO_3^- in the products. Since you need to have two NO_3^- in the reactants, place a coefficient of 2 in front of $AgNO_3(aq)$.

   $CaCl_2(aq) + 2AgNO_3(aq) \longrightarrow AgCl(s) + Ca(NO_3)_2(aq)$
3. There are now two silver ions in the reactants. You know you need to have two silver ions in the products to balance these in the equation. Therefore, place a coefficient of 2 in front of $AgCl(s)$.

   $CaCl_2(aq) + 2AgNO_3(aq) \longrightarrow 2AgCl(s) + Ca(NO_3)_2(aq)$

   Notice that adding the coefficient has also balanced the number of chloride ions. The number of calcium ions also remains balanced.
4. As a final check, count the number of each type of atom on the left side of the equation and on the right side of the equation. Make sure they are the same.

Ion	Reactant	Product
Ca^{2+}	1	1
Ag^+	2	2
Cl^-	2	2
NO_3^-	2	2

Practice Problems

Balance each of the following skeleton equations.

1. $Li(s) + Br_2(g) \longrightarrow LiBr(s)$
2. $Al(s) + CuO(s) \longrightarrow Al_2O_3(s) + Cu(s)$
3. $Pb(NO_3)_2(aq) + K_3PO_4(aq) \longrightarrow KNO_3(aq) + Pb_3(PO_4)_2(s)$

For each of the following reactions, write a word equation, a skeleton equation, and a balanced chemical equation. Include the states of matter.

4. Nitrogen monoxide gas reacts with oxygen gas to form nitrogen dioxide gas.
5. Solid copper reacts with aqueous silver nitrate to form solid silver and aqueous copper(II) nitrate.
6. Potassium sulfate and silver nitrate, both dissolved in water, react to form solid silver sulfate and dissolved potassium nitrate.