Understanding Chemical Equations

Connections

Have you ever…

- Seen the result of mixing baking soda and vinegar?
- Used friction to light a match?
- Seen a car eaten through by rust?

Chemical equations model chemical reactions, which cause many of the changes in the world, as well as most of the changes within your body. Everything from breathing, to cooking, to charging a smartphone, is governed by some form of chemical reaction.

A chemical reaction is the process by which one chemical substance is changed into another. Chemical bonds break and form to create a new substance. Here are a few helpful terms:

- **Atom:** An atom is the smallest unit of a chemical element. In chemical equations, atoms are represented by one capital letter, or a pairing of one capital letter and one lowercase letter. **Example:** H represents hydrogen. Cl represents chlorine.
- **Molecule:** A molecule is a group of atoms bonded together into a chemical compound. **Example:** Hydrogen and chlorine can form HCl, a Hydrogen Chloride molecule.
- **Reactants:** Reactants are the chemical substances changed by a chemical reaction. They are found on the left-hand side of a chemical equation.
- **Products:** Products are the chemical substances formed by a chemical reaction. They are found on the right-hand side of a chemical equation.
- **Yield:** A chemical equation doesn't use an equal sign. It uses a right-pointing arrow that means "yield." The reactants yield products.
- **Law of Conservation of Mass:** This law states that a chemical reaction can neither create nor destroy matter, only rearrange it. For this reason, the reactants of a chemical equation must yield products of equal mass. This is why it is called a chemical equation. The two sides are equal.

Balancing a Chemical Equation

For a chemical equation to balance, the reactant side of the equation must have the same number of atoms, of each kind present, on the product side. To balance a chemical equation, you may add molecules to either side of the equation, or both, but you cannot *remove* molecules, nor may you add or remove individual atoms.

As part of a correspondence course in chemistry, Melinda is trying to balance a chemical equation. On the reactant side she has a hydrogen molecule (H_2) added to a chlorine molecule (Cl_2). On the product side of the equation she has one molecule of hydrogen chloride (HCl).

The chemical equation symbolically represents hydrogen and chlorine combining to yield hydrogen chloride. It looks like this:

$$H_2 + Cl_2 \rightarrow HCl$$

How can Melinda balance this equation?

Calculate the Number of Atoms

To determine if the equation balances, calculate the number of atoms of each type on each side of the equation. To be balanced, a chemical equation must have the same number of atoms of each type on the product side that it has on the reactant side.

If an atom includes a subscript number, this represents the number of that atoms present of that kind. (**Example:** A hydrogen peroxide molecule, H_2O_2, includes two hydrogen atoms and two oxygen atoms.)

If there is more than one molecule, a coefficient represents the number of molecules. (**Example:** $3H_2O_2$ indicates there are three hydrogen peroxide molecules, and therefore six (2×3) hydrogen atoms and six (2×3) oxygen atoms.)

1. How many of each type of atom are present on each side of Melinda's equation?

Atom Type	Number on Reactant Side	Number on Product Side

The reactant side is the left side of the equation. In Melinda's equation, the hydrogen molecule contains two hydrogen atoms. The chlorine molecule contains two chlorine molecules. That's a total of four atoms: two hydrogen atoms and two chlorine atoms.

The product side is the right side of the equation. On the product side, the hydrogen chloride molecule has one hydrogen atom and it also has one chlorine atom, for a total of two atoms on the product side. The equation does not balance.

Atom Type	Number on Reactant Side	Number on Product Side
H	$1 \text{ molecule} \times 2 \text{ atoms} = 2$	$1 \text{ molecule} \times 1 \text{ atom} = 1$
Cl	$1 \text{ molecule} \times 2 \text{ atoms} = 2$	$1 \text{ molecule} \times 1 \text{ atom} = 1$

Calculate Missing Atoms

Determine how many atoms, of each kind, are missing from the equation to have the same number on each side.

2. How many atoms, of each kind, are missing from the equation?

The reactant side has twice the number of atoms as the product side. You can make a quick table to track how many atoms each side has by amount.

Reactant Side	Product Side
(H)(H)	(H)
(Cl)(Cl)	(Cl)

From the table, you can clearly see that the product side is missing one hydrogen atom and one clorine atom.

Add Molecules to Balance the Equation

You cannot remove anything from the equation, nor can you add individual atoms. You may only add molecules to one or both sides of the equation to bring it into balance. As a rule of thumb, begin by looking at the molecules you already have in the equation. Add one type of molecule at a time, and keep track of how many atoms you have on each side.

? **3.** What molecules should Melinda add to balance the equation?

The product side of the equation is missing a hydrogen atom and a chlorine atom. You can't add a hydrogen or chlorine molecule to the product side, because each molecule has two atoms. That would be too many atoms. You only need one atom of each kind.

A hydrogen chloride molecule has one hydrogen atom and one chlorine atom, which is exactly what the product side needs. By adding a coefficient of two to the hydrogen chloride molecule, you can indicate that there are two hydrogen chloride molecules.

The result is a balanced chemical equation:

$$H_2 + Cl_2 \rightarrow 2HCl$$

The reactant side has two hydrogen atoms and two chlorine atoms. Thanks to the coefficient of two, the product side now has twice as many hydrogen chloride molecules, and also twice as many atoms. The chemical equation now balances. It represents that one hydrogen molecule combines with one chlorine molecule to form two hydrogen chloride molecule.

Build Your Science Skills

Is it one atom or two?

It can be difficult to tell the difference between two different atoms represented by capital letters, and a single atom represented by two letters.

Remember, if you see two different capital letters, side by side, that's two different atoms.

If you see a capital letter followed by a lowercase letter, that's one atom.

Example: The molecule NH_4NO_3 (ammonium nitrate) includes three types of atoms: N (nitrogen), H (hydrogen) and O (oxygen).

Practice It!

Complete the following practice questions on balancing chemical equations.

1. $2FeCl_3 + MgO \rightarrow Fe_2O_3 + 3MgCl_2$

   a. How many atoms of each type are on each side of this equation?

   b. How many atoms of each kind are missing from the equation? On which side?

   c. After adding molecules to balance the equation, what is the final equation?

2. $3Li + 2H_3PO_4 \rightarrow 3H_2 + 2Li_3PO_4$

   a. How many atoms of each type are on each side of this equation?

   b. How many atoms of each kind are missing from the equation? On which side?

   c. After adding molecules to balance the equation, what is the final equation?

Know How to Symbolically Represent Atoms: Some Common Symbols for Atoms

H | Hydrogen	He | Helium	Li | Lithium	Be | Beryllium
B | Boron	C | Carbon	N | Nitrogen	O | Oxygen
F | Fluorine	Ne | Neon	Na | Sodium	Mg | Magnesium
Al | Aluminum	Si | Silicon	P | Phosphorus	S | Sulfur
Cl | Chlorine	Ar | Argon	K | Potassium	Ca | Calcium
Ti | Titanium	Cr | Chromium	Mn | Manganese	Fe | Iron
Co | Cobalt	Ni | Nickel	Cu | Copper	Zn | Zinc
As | Arsenic	Ag | Silver	Sn | Tin	I | Iodine
Pt | Platinum	Au | Gold	Hg | Mercury	Pb | Lead

3. $P_4 + O_2 \rightarrow P_2O_5$

a. How many atoms of each type are on each side of this equation?

b. How many atoms of each kind are missing from the equation? On which side?

c. After adding molecules to balance the equation, what is the final equation?

4. $NH_4NO_3 \rightarrow N_2O + H_2O$

a. How many atoms of each type are on each side of this equation?

b. How many atoms of each kind are missing from the equation? On which side?

c. After adding molecules to balance the equation, what is the final equation?

5. $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

a. How many atoms of each type are on each side of this equation?

b. How many atoms of each kind are missing from the equation? On which side?

c. After adding molecules to balance the equation, what is the final equation?

Check Your Skills

When you see this icon, you may use a calculator.

Balance the following equations by entering a coefficient in the space provided before each molecule. If the coefficient is one, leave the box blank.

1. ______ SnO_2 + ______ H_2 → ______ Sn + ______ H_2O

2. ______ KNO_3 + ______ H_2CO_3 → ______ K_2CO_3 + ______ HNO_3

3. ______ $SeCl_6$ + ______ O_2 → ______ SeO_2 + ______ Cl_2

4. $4NH_3 + 5O_2$ → ______ NO + ______ H_2O

5. $2AlBr_3 + 3Cl_2$ → ______ $AlCl_3$ + ______ Br_2

6a. ______ Cr + ______ O_2 → ______ Cr_2O_3

6b. What does the above chemical equation represent?

a. Chromium and oxygen yielding chromium (III) oxide

b. Chromium and oxygen molecules separating into atoms

c. Chromium and oxygen atoms yielding chromium and oxygen molecules

d. Chromium (III) oxide forming from free chromium and oxygen atoms that aren't bound into molecules

7. Which equation correctly symbolically represents ethane (C_2H_6) and oxygen creating carbon dioxide and water?

a. $2C_2H_6 + 6O_2 \rightarrow 4CO_2 + 4H_2O$

b. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

c. $C_2H_6 + 2O_2 \rightarrow CO_2 + 5H_2O$

d. $C_2H_6 + O_2 \rightarrow 3CO_2 + H_2O$

8. Which equation correctly symbolically represents aluminum oxide (Al_2O_3) breaking down into aluminum and oxygen?

a. $Al_2O_3 \rightarrow Al + O_2$

b. $Al_2O_3 \rightarrow 2Al + 3O_2$

c. $2Al_2O_3 \rightarrow 4Al + 3O_2$

d. $2Al_2O_3 \rightarrow 2Al + O_2$

Remember the Concept

To balance a chemical equation:

- Calculate the number of atoms of each type on each side of the equation.
- Determine how many atoms are missing (if any) and on which side of the equation.
- Add one or more molecules to the equation to bring it into balance.

Remember, you must add complete molecules, not individual atoms.

Understanding Chemical Equations

Balancing a Chemical Equation

Practice It!

1a. Calculate the number of atoms by multiplying the number of molecules (the coefficient) by the number of atoms in the molecule.

The reactant side has 10 atoms: 2 Fe (iron) atoms, 6 Cl (chlorine) atoms, 2 Mg (magnesium) atom, and 1 O (oxygen) atom.

The product side has 14 atoms: 2 Fe (iron) atoms, 6 Cl (chlorine) atoms, 3 Mg (magnesium) atoms, and 3 O (oxygen) atoms.

Reactants	Products
(Fe)(Fe)	(Fe)(Fe)
(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)	(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)
(Mg)(Mg)	(Mg)(Mg)(Mg)
(O)	(O)(O)(O)

1b. After comparing the atoms present on each side of the equation, you can see that the reactant is missing 2 Mg atoms and 2 O atoms.

1c. $2FeCl_3 + 3MgO \rightarrow Fe_2O_3 + 3MgCl_2$

To add two oxygen atoms and two magnesium atoms to the reactant, you can add two additional MgO molecules, for a total of three.

2a. The reactant side has 19 atoms: 3 Li (lithium) atoms, 6 H (hydrogen) atoms, 2 P (phosphorous), and 8 O (oxygen) atoms. The product side has 22 atoms: 6 Li (lithium) atoms, 6 H (hydrogen) atoms, 2 P (phosphorous) atoms, and 8 O (oxygen) atoms.

Reactants	Products
(Li)(Li)(Li)	(Li)(Li)(Li)(Li)(Li)(Li)
(H)(H)(H)(H)(H)(H)	(H)(H)(H)(H)(H)(H)
(P)(P)	(P)(P)
(O)(O)(O)(O)(O)(O)(O)(O)	(O)(O)(O)(O)(O)(O)(O)(O)

2b. After comparing the atoms present on each side of the equation, you can see that the reactant side is missing 3 Li atoms.

2c. $6Li + 2H_3PO_4 \rightarrow 3H_2 + 2Li_3PO_4$

To add three lithium atoms to the reactants, all that's needed is to add three lithium molecules, which each have one lithium atom.

3a. This equation represents phosphorus (P_4) combining with oxygen to form phosphorus pentoxide ("pentoxide" meaning five oxygen).

The reactant side has 6 atoms: 4 P (phosphorous) atoms and 2 O (oxygen) atoms. The product side has 7 atoms: 2 P (phosophorous) atoms and 5 O (oxygen) atoms.

Reactants	Products
(P)(P)(P)(P)	(P)(P)
(O)(O)	(O)(O)(O)(O)(O)

3b. After comparing the atoms present on each side of the equation, you can see that the reactant side is missing 3 oxygen atoms, and the product side is missing 2 phosphorous atoms.

3c. $P_4 + 5O_2 \rightarrow 2P_2O_5$

Since you can only add one oxygen molecule at a time, you can only add two oxygen atoms at a time. You can't get five oxygen atoms on the left side, so you'll need the least common multiple of 2 and 5: 10 oxygen atoms. That means five oxygen molecules on the left side, and one additional phosphorus pentoxide molecule on the right. This balances the equation.

You could also start by adding phosphorous. To add two phosphorus atoms to the product side, you need to add one whole molecule of phosphorus pentoxide. That means adding five more oxygen atoms, for a total of 10. Add four oxygen molecules to the reactant side to get a total of 10 oxygen atoms.

4a. Notice that on the reactant side of the equation, you need to count two nitrogen atoms in the same molecule. On the product side, you need to count two oxygen atoms in different molecules. The reactant side has 9 atoms: 2 N (nitrogen) atoms, 4 H (hydrogen) atoms, and 3 O (oxygen) atoms. The product side has 7 atoms: 2 N (nitrogen) atoms, 2 O (oxygen) atoms, and 2 H (hydrogen) atoms.

Reactants	Products
(N)(N)	(N)(N)
(H)(H)(H)(H)	(H)(H)
(O)(O)(O)	(O)(O)

4b. After comparing the atoms present on each side of the equation, you can see that the product side is missing two hydrogen atoms and one oxygen atom.

4c. $NH_4NO_3 \rightarrow N_2O + 2H_2O$

Add one H_2O molecule to the product side to add two hydrogen atoms and one oxygen atom and balance the equation.

5a. The reactant side has 16 atoms: 4 C (carbon) atoms, 10 H (hydrogen) atoms, and 2 O (oxygen) atoms. The product side has 7 atoms: 1 C (carbon) atom, 3 O (oxygen) atoms, and 2 H (hydrogen) atoms.

Reactants	Products
(C)(C)(C)(C)	(C)
(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)	(H)(H)
(O)(O)	(O)(O)(O)

5b. The product side is missing three carbon atoms and eight hydrogen atoms. The reactant side is missing one oxygen atom. Both sides of the equation need adjustment.

5c. $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

This is a tricky one, as balancing the equation requires adding many molecules to both sides of the equation. You need at least three more carbon atoms in the product, so add three additional carbon dioxide (CO_2) molecules, for a total of four:

$C_4H_{10} + O_2 \rightarrow 4CO_2 + H_2O$

Reactants	Products
(C)(C)(C)(C)	(C)(C)(C)(C)
(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)	(H)(H)
(O)(O)	(O)(O)(O)(O)(O)(O) (O)(O)(O)

You also need eight hydrogen atoms in the product, so add four more water (H_2O) molecules, for a total of five.

$C_4H_{10} + O_2 \rightarrow 4CO_2 + 5H_2O$

Reactants	Products
(C)(C)(C)(C)	(C)(C)(C)(C)
(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)	(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)
(O)(O)	(O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)

Now, you need to add more oxygen to the reactants. You need 11 more oxygen atoms, but you can only add two oxygen atoms at a time, because an oxygen molecule has two atoms. The lowest multiple of two and 13 is 26, so you'll need 26 oxygen atoms. That's 13 total molecules.

$C_4H_{10} + 13O_2 \rightarrow 4CO_2 + 5H_2O$

Reactants	Products
(C)(C)(C)(C)	(C)(C)(C)(C)
(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)	(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)
(O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)	(O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)

To get that much oxygen on the opposite side, you'll need double. You can double the carbon dioxide and water molecules. That means doubling the carbon and hydrogen, too, so to balance it, you'll need two C_4H_{10} (butane) molecules.

$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Reactants	Products
(C)(C)(C)(C)(C)(C) (C)(C)	(C)(C)(C)(C)(C)(C) (C)(C)
(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)(H)(H) (H)(H)(H)(H)(H)(H) (H)(H)	(H)(H)(H)(H)(H)(H) (H)(H)(H)(H)(H)(H) (H)(H)(H)(H)(H)(H) (H)(H)
(O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)	(O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)(O)(O)(O)(O) (O)(O)

Complex chemical equations like this one may be easier to do using algebra than simply by counting atoms and adding molecules, but you can still try going through step-by-step and adding molecules until you get a balanced equation.

Check Your Skills

1. $SnO_2 + 2H_2 \rightarrow Sn + 2H_2O$

This equation represents tin dioxide and hydrogen combining to create tin and water. When there is one molecule of each, the reactants contain one tin atom, two oxygen atoms, and two hydrogen atoms. The products contain one tin atom, two hydrogen atoms, and one oxygen atoms.

Reactants	Products
(Sn)	(Sn)
(O)(O)	(O)
(H)(H)	(H)(H)

To add more oxygen to the products, you need to add a whole water molecule:

Reactants	Products
(Sn)	(Sn)
(O)(O)	(O)(O)
(H)(H)	(H)(H)(H)(H)

Since the equation is still unbalanced, you need to add an additional hydrogen molecule to the reactants to get a balanced equation:

Reactants	Products
(Sn)	(Sn)
(O)(O)	(O)(O)
(H)(H)(H)(H)	(H)(H)(H)(H)

2. $2KNO_3 + H_2CO_3 \rightarrow K_2CO_3 + 2HNO_3$

This equation represents potassium nitrate combining with carbonic acid to form potassium carbonate and nitric acid. When there is only one molecule of each, the equation contains the folowing atoms:

Reactants	Products
(K)	(K)(K)
(N)	(N)
(O)(O)(O)(O)(O)(O)	(O)(O)(O)(O)(O)(O)
(C)	(C)
(H)(H)	(H)

To get more hydrogen in the product, you need to add another molecule of nitric acid. To get more potassium in the reactants, you need to add another molecule of potassium nitrate. This balances the equation:

Reactants	Products
(K)(K)	(K)(K)
(N)(N)	(N)(N)
(O)(O)(O)(O)(O)(O) (O)(O)(O)	(O)(O)(O)(O)(O)(O) (O)(O)(O)
(C)	(C)
(H)(H)	(H)(H)

3. $SeCl_6 + O_2 \rightarrow SeO_2 + 3Cl_2$

This equation represents selenium hexachloride ("hexachloride" meaning 6 chlorine) combining with oxygen to form selenium dioxide ("dioxide" meaning two oxygen) and chlorine.

When there is one molecule of each, the equation has the following atoms:

Reactants	Products
(Se)	(Se)
(Cl)(Cl)(Cl)(Cl)(Cl) (Cl)	(Cl)(Cl)
(O)(O)	(O)(O)

Add two more molecules of chlorine, for a total of three, to the products to balance the equation:

Reactants	Products
(Se)	(Se)
(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)	(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)
(O)(O)	(O)(O)

4. $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

This equation represents amonia (NH_3) combining with oxygen to form nitric oxide and water.

The coefficients of the reactants are given. The starting equation has the following atoms:

Reactants	Products
(N)(N)(N)(N)	(N)
(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)	(H)(H)
(O)(O)(O)(O)(O)(O)(O)(O)(O)(O)	(O)(O)

To get four nitrogen atoms in the product, you need three more nitric oxide molecules, for a total of four.

To get twelve hydrogen atoms in the product, you need five more water molecules, for a total of six.

This adds eight more oxygen atoms, for a total of ten oxygen atoms, which balances the equation.

Reactants	Products
(N)(N)(N)(N)	(N)(N)(N)(N)
(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)	(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)(H)
(O)(O)(O)(O)(O)(O)(O)(O)(O)(O)	(O)(O)(O)(O)(O)(O)(O)(O)(O)(O)

5. $2AlBr_3 + 3Cl_2 \rightarrow 2AlCl_3 + 3Br_2$

This equation represents aluminum bromide and clorine combining to yield aluminum chloride and bromine.

The coefficients of the reactants are given. The starting equation has the following atoms:

Reactants	Products
(Al)(Al)	(Al)
(Br)(Br)(Br)(Br)(Br)(Br)	(Br)(Br)
(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)	(Cl)(Cl)(Cl)

To get six bromine atoms in the product, you need two more bromine molecules (each with two atoms), for a total of three molecules.

To get two aluminum atoms in the product, you need one more aluminum chloride molecule, for a total of two. This also provides three additional chlorine molecules, which balances the equation.

Reactants	Products
(Al)(Al)	(Al)(Al)
(Br)(Br)(Br)(Br)(Br)(Br)	(Br)(Br)(Br)(Br)(Br)(Br)
(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)	(Cl)(Cl)(Cl)(Cl)(Cl)(Cl)

6a. $4Cr + 3O_2 \rightarrow 2Cr_2O_3$

This equation represents chromium combining with oxygen to form chromium (III) oxide.

With one of each type of molecule, the chemical equation has these atoms:

Reactants	Products
(Cr)	(Cr)(Cr)
(O)(O)	(O)(O)(O)

Since you can only add one oxygen molecule at a time, you can only add two oxygen atoms at a time. You can't get three oxygen atoms on the left side, so you'll need the least common multiple of 2 and 3: 6 oxygen atoms. That means three oxygen molecules on the left side, and one additional chromium oxide molecule on the right. To balance the equation, you need four chromium molecules.

Reactants	Products
(Cr)(Cr)(Cr)(Cr)	(Cr)(Cr)(Cr)(Cr)
(O)(O)(O)(O)(O)(O)	(O)(O)(O)(O)(O)(O)

6b. a. Chromium and oxygen yielding chromium (III) oxide

Even though you might not be familiar with chromium oxide, you can identify chromium and oxygen. The right hand side of the equation has a molecule made up of both, not separating them or yielding separate molecules of chromium and oxygen atoms. The reactants are molecules of chromium and oxygen, and they yield a molecule that contains both chromium and oxygen.

7. b. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

This is the only balanced equation representing ethane and oxygen combining to form carbon dioxide and water. There are four carbon atoms, 12 hydrogen atoms, and 14 oxygen atoms on each side of the equation.

8. c. $2Al_2O_3 \rightarrow 4Al + 3O_2$

This is the only balanced equation representing aluminum oxide breaking down into aluminum and oxygen. There are four aluminum atoms and six oxygen atoms on each side of the equation.