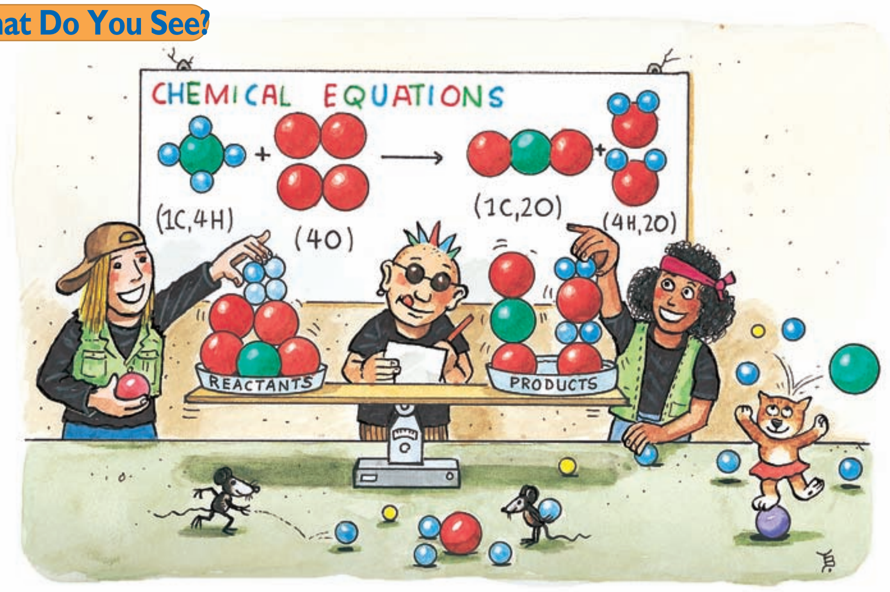
Activity 2 Balancing Chemical Equations

What Do You See?



GOALS

In this activity you will:

- Explain the purpose of balancing a chemical equation.
- Relate the balancing of an equation to the Law of Conservation of Matter.
- Balance a chemical equation.

What Do You Think?

The word "balance" is used in both literary and scientific contexts. Consider the following statements.

Arthur Wellesley, Duke of Wellington, said:

"It is very true that I have said that I considered Napoleon's presence in the field equal to forty thousand men in the balance."

Plutarch, a Greek biographer who lived from 46-120 A.C.E., wrote:

"Prosperity is no just scale; adversity is the only balance to weigh friends."

- **What is meant by the word "balance" in each of these contexts?**
- **How might this be related to the concept of balanced equations in chemistry?**

Record your ideas about these questions in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Is Matter Really Conserved?

1. Look at the following chemical reaction:

   $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

   It is one of the reactions from the previous activity. You will be given the following:

- **calcium carbonate, $CaCO_3$**
- **hydrochloric acid, HCl**
- **balloon**
- **beaker**
- **Erlenmeyer flask**
- **resealable plastic bag**
- **graduated cylinder**
- **rubber bands**
- **balance**

2. Design an experiment to find out if the mass of the starting materials is equal to the mass of the ending materials.

   a) Record your procedure in your *Active Chemistry* log.

   b) Be sure to make a table in which to record your data.

3. Have your procedure approved by your teacher first before beginning.

4. With your teacher's permission, carry out your procedure.

   a) Record your results.

Safety goggles and apron must be worn *at all times* in a chemistry lab.

Be careful with the chemicals used. Clean up any spills immediately.

Wash your hands and arms thoroughly after the activity.

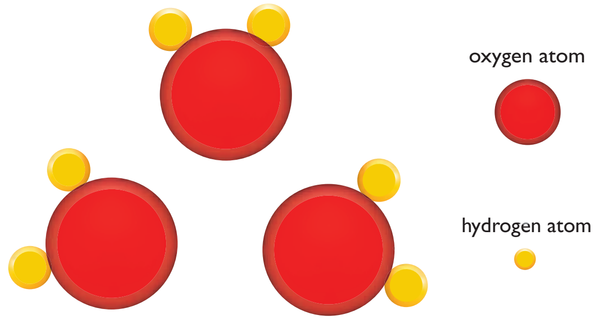
Part B: Visualizing Chemical Formulas and Balancing Reactions

1. It is helpful to be able to visualize the number of elements and their arrangement either in your head or on paper when balancing an equation. To help you begin to visualize atoms and molecules, an example of three molecules of H_2O ($3H_2O$) is shown. Use Bingo markers or other colored circles and blank paper to illustrate each of the molecules below. Be sure to use a different color for each element.

   a) $4Fe_2O_3$ b) $2KNO_3$ c) $6Al_2(SO_4)_3$

2. Next, use the Bingo markers to illustrate each of the chemical equations below. Be sure to use the same color for the same atom on the input and output sides of the equation. It will be helpful to make a key, as shown in the $3H_2O$ example.

Three Water Molecules



   a) hydrochloric acid + zinc → zinc chloride + hydrogen

   __ HCl + __ Zn → __ $ZnCl_2$ + __ H_2

   b) sodium + fluorine → sodium fluoride

   __ Na + __ F_2 → __ NaF

   c) sodium chlorate → sodium chloride + oxygen

   __ $NaClO_3$ → __ NaCl + __ O_2

   d) hydrochloric acid + calcium carbonate → water + carbon dioxide + calcium chloride

   __ HCl + __ $CaCO_3$ →
   __ H_2O + __ CO_2 + __ $CaCl_2$

e) lead nitrate + sodium chloride → lead chloride + sodium nitrate

__ $Pb(NO_3)_2$ + __ $NaCl$ → __ $PbCl_2$ + __ $NaNO_3$

Tip #1: NO_3 can be treated as a single item since it's the same on both the left and the right. There are two NO_3 items on the left and one on the right.

f) copper + silver nitrate → copper (II) nitrate + silver

__ Cu + __ $AgNO_3$ → __ $Cu(NO_3)_2$ + __ Ag

g) aluminum sulfate + calcium hydroxide → aluminum hydroxide + calcium sulfate

__ $Al_2(SO_4)_3$ + __ $Ca(OH)_2$ → __ $Al(OH)_3$ + __ $CaSO_4$

Tip #2: Remember to write the parentheses ( ) around an item if there is more than one of it in a chemical. $Al(OH)_3$ and $AlOH_3$ mean different things. The first one means there are 3 of the OH item in the chemical. The second one means there is one O and there are 3 H's. Likewise, write $Al_2(SO_4)_3$, not Al_2SO_{43}.

h) iron + water → iron (II, III) oxide + hydrogen

__ Fe + __ H_2O → __ Fe_3O_4 + __ H_2

i) methane + oxygen → carbon dioxide + water

__ CH_4 + __ O_2 → __ CO_2 + __ H_2O

3. Use the Bingo markers to add the necessary atoms and/or molecules to make the equations balanced. The type and number of each atom of the reactants' side must be identical to the type and number of each atom on the products' side. It is important to use only whole numbers as coefficients since the coefficient represents the number of atoms or molecules present. Once you have each equation balanced, prove that matter is conserved by making sure the input equals the output for each item. Write the balanced equations in your *Active Chemistry* log.

Part C: Using Chemical Symbols to Balance Equations

1. Now that you have mastered the visualization of reactions, you will work in symbolic terms. One way to balance chemical equations is to make a list that compares how many of each atom exist on the reactant (left) and product (right) sides of the arrow.

   When a chemical reaction occurs, the amount of matter that is present before the reaction occurs is still present after the reaction. The atoms have simply rearranged, not changed. You write coefficients in front of each chemical substance to indicate how many of each substance are necessary for the equation to be balanced. (When there is exactly one, the coefficient is assumed to be "1" and is not written.)

   a) What are the coefficients of each of the substances (starting materials and ending materials) in the following chemical equation?

   $CaCO_3 + 2HCl \rightarrow$
   $CaCl_2 + H_2O + CO_2$

2. In understanding equations of chemical reactions, there are three considerations. The first is the chemical formula itself. This tells

you exactly how many atoms of each element are in the compound. This cannot be changed. The second are the subscripts that appear in the formulas. The subscripts tell you exactly how many atoms or groups of atoms are present in one formula unit. This also cannot be changed. (If the subscript is "1" it is not written.) Finally, the third consideration is the coefficient. This tells you how many units of the entire compound take part in the reaction. In "$3H_2O$," the 3 is the coefficient, which tells you there are three water molecules (H_2O). The 2 is a subscript, that tells you that there are two hydrogen atoms in each water molecule. The total number of hydrogen atoms in $3H_2O$ is six. The coefficient is the only number that can be changed in balancing an equation.

Figure out the number of each item in each of the following:

a) How many O's are there in $4Fe_2O_3$?

b) How many NO_3's are there in $2KNO_3$?

c) How many SO_4's are there in $6Al_2(SO_4)_3$?

d) Write down some rules to help you remember how to figure out how many of an item there are.

3. In the reaction:

$CaCO_3 + 2HCl \rightarrow$
$CaCl_2 + H_2O + CO_2$

you can list the numbers of each atom on the reactant and product side, as shown on the table below.

Atom/Ion	Reactant	Product
Ca	1 (in $CaCO_3$)	1 (in $CaCl_2$)
C	1 (in $CaCO_3$)	1 (in CO_2)
O	3 (in $CaCO_3$)	3 (1 in H_2O and 2 in CO_2)
H	2 (in 2HCl)	2 (in H_2O)
Cl	2 (in 2HCl)	2 (in $CaCl_2$)

The number of each atom remains constant. Atoms are recombining in the reaction, but are not themselves changing.

4. The following is a set of unbalanced equations. Your teacher will assign your group one equation. Your task will be to analyze the equation, balance it using chemical symbols, and to write a procedure for balancing equations.

Helpful hints are provided in *Steps 5* and 6.

Group 1:

$Pb(NO_3)_2$	+	$(NH_4)_2SO_4$	$\rightarrow$	$PbSO_4$	+	NH_4NO_3
lead nitrate	*and*	*ammonium sulfate*	*yield*	*lead (II) sulfate*	*and*	*ammonium nitrate*

Group 2:

$Cu(NO_3)_2$	+	Na_3PO_4	$\rightarrow$	$Cu_3(PO_4)_2$	+	$NaNO_3$
copper (II) nitrate	*and*	*sodium phosphate*	*yield*	*copper (II) phosphate*	*and*	*sodium nitrate*

Group 3:

$Fe(NO_3)_3$	+	K_2CO_3	→	$Fe_2(CO_3)_3$	+	KNO_3
iron (III) nitrate	*and*	*potassium carbonate*	*yield*	*iron (III) carbonate*	*and*	*potassium nitrate*

Group 4:

$AlCl_3$	+	$Pb(NO_3)_2$	→	$PbCl_2$	+	$Al(NO_3)_3$
aluminum chloride	*and*	*lead (II) nitrate*	*yield*	*lead (II) chloride*	*and*	*aluminum nitrate*

Group 5:

$Al_2(CO_3)_3$	+	HCl	→	$AlCl_3$	+	H_2O	+	CO_2
aluminum carbonate	*and*	*hydrogen chloride*	*yield*	*aluminum chloride*	*and*	*water*	*and*	*carbon dioxide*

Group 6:

$Al(NO_3)_3$	+	K_3PO_4	→	$AlPO_4$	+	KNO_3
aluminum nitrate	*and*	*potassium phosphate*	*yield*	*aluminum phosphate*	*and*	*potassium nitrate*

Group 7:

$Ba(NO_3)_2$	+	$Cr_2(SO_4)_3$	→	$BaSO_4$	+	$Cr(NO_3)_3$
barium nitrate	*and*	*chromium (III) sulfate*	*yield*	*barium sulfate*	*and*	*chromium (III) nitrate*

5. Consider the statement: "The chemical reaction is not balanced." What does this mean?

   a) Write down your answer to this question in your *Active Chemistry* log.

   b) What are the atoms to consider in the equation your group was assigned?

   c) Do the same type and number of atoms exist on both sides of the arrow?

6. Copy the chemical equation you were assigned into your *Active Chemistry* log. Make a table like the following one beneath for your equation:

   a) Fill in the "Atom/Ion" column.

Atom/Ion	Reactant	Product

   b) Look at the reactants (starting materials on the left side of the arrow). Count how many of each element there are and write it in the table.

   c) Next, look at the products (ending materials on the right side of the arrow). Count how many of each element there are and write it in the table.

   d) What's wrong with the balance?

   e) Change the coefficients in a logical way to balance the equation.

   f) Describe what happens when a chemical reaction is balanced.

7. Now that you have practiced balancing equations several times, you have a system in place for how to do it.

   a) With your group, write down a list of step-by-step instructions that you could give to someone to balance equations.

Chem Talk

LAW OF CONSERVATION OF MATTER

Balanced chemical equations are an example of the **Law of Conservation of Matter.** You may already have learned a formal definition for this principle: matter cannot be created or destroyed, but it can change form. In the case of chemical reactions, this means that the same quantity of each element must enter and exit a chemical reaction; however, the elements can be associated with different elements on each side. When chemical equations are written, the quantity of an element on the reactant side must equal the quantity of that element on the product side, although the atoms of the element may be bonded differently.

Chem Words

Law of Conservation of Matter: the amount of matter present before and after a chemical change remains the same.

Historical Background of Ideas about the Conservation of Matter

Scientists haven't always known that matter is conserved. In fact, about 2500 years ago they were struggling with this concept. In Greece, several philosophers, including Democritus, Heraclitus, and Aristotle, were among the first to postulate that there was an "equivalence of matter." Heraclitus (530–470 B.C.) said of the changing forms of water that "Sea is liquefied and measured into the same proportion as it had before it became Earth." Parmenides (born circa 510 B.C.) argued that "Being (that which exists) is conserved, that nothing comes from nothing." Democritus (460–370 B.C.) made up the term "atom" to mean the smallest part of matter that is unchanging and cannot be cut into smaller pieces. Aristotle (384–322 B.C.) laid the foundation for the Western study of science by arguing that there were four "atoms:" fire, earth, water and air.

Very little that is historically documented was added to the understanding of the Law of Conservation of Matter for many centuries. Nasiraddin Tusi (born in A.D.1201 in what is now Iran) wrote that "a body of matter cannot disappear completely. It only changes its form, condition, composition, color, and other properties and turns into a different complex or elementary matter." Western science did not recognize the principle until Antoine-Laurent Lavoisier (1743–1794) in France and Mikhail Lomonosov (1711–1765) in Russia stated it explicitly.

Checking Up

1. State the Law of Conservation of Matter. Then, explain in your own words what it means.
2. What is the smallest particle of matter with unique properties called?

What Do You Think Now?

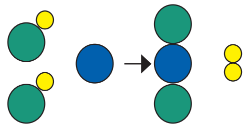
At the beginning of this activity you were asked what was meant by the word "balance."

In which of the two quotes from the beginning of the activity do you now think the use of the word "balance" is closer to the meaning of the word when it is used to describe chemical equations?

Chem Essential Questions

What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
Explain how your observations in this activity provide evidence that supports the Law of Conservation of Matter.	*Explain how you know that the following equation is balanced:* $Pb(NO_3)_2 + 2NaCl \rightarrow PbCl_2 + 2NaNO_3$	*Here are two symbolic ways of depicting a reaction:* $2HCl_{(aq)} + Zn_{(s)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$  *Make and label a similar drawing for the equation:* $CaCO_3 \rightarrow CaO + CO_2$

How do you know?

Describe how the outcome of your experiment in *Part A* would have been different if balloons and resealable plastic bags had not been provided. Would the Law of Conservation of Matter still have been true?

Why do you believe?

Measuring the mass of an effervescent antacid table and the mass of water before and after the tablet dissolves seems to indicate that mass is not conserved. Explain what is happening to the matter that causes the law to appear to be violated. Describe how you could design an experiment to see if the amount of matter present actually changes.

Why should you care?

Balancing equations indicates the amount of reactants required to yield a specific amount of product. How would this be important if you chose to generate gas for your *Chemical Dominoes* toy?

Reflecting on the Activity and the Challenge

If you are using a chemical reaction to blow up a balloon with a gas that tips a lever (or to accomplish another task in your apparatus), then you will need to know how much of the starting materials to use to get the balloon to blow up to a certain size. As you learned in this activity, starting with a certain number of molecules of a substance does not mean the reaction will produce that number of molecules of a product. You have to consider how many atoms of elements are needed to form the molecules of the reactants and how many atoms are needed to form the molecules of the products.

While the number of atoms of each element will not change, the number of molecules that are formed may be different. It may take two of an input item to make three of an output item, or one of an input item to make two of an output item. These numbers, which are really coefficients, can only be determined by balancing the chemical equation for the reaction. So, if you want to use a particular chemical reaction to accomplish a task in your apparatus, you will have to be able to balance the chemical equation that represents the reaction so you will know how much input (starting materials) to use.

Chem to Go

1. Which of these equations is balanced, and which is not balanced? Explain how you can tell.

   a) $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

   b) $2MgCO_3 + H_2SO_4 \rightarrow 2MgSO_4 + H_2O + 2CO_2$

2. The following equation is incorrectly balanced. What mistake was made in balancing it?

   $2AgNO_3 + 3CaCl_2 \rightarrow 3Ca(NO_3)_2 + 2AgCl$

3. What is wrong with the following chemical equation?

   $Na_2SO_4 + BaCl_2 \rightarrow Cl_2 + BaSO_4$

4. The input side of a chemical equation is:

   $KMnO_4 + I_2 \rightarrow$

   What elements must be on the output side?

5. Balance the following equations using the method that works best for you.

   a) $Na + Cl_2 \rightarrow NaCl$

   b) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

   c) $MgCO_3 + HBr \rightarrow MgBr_2 + CO_2 + H_2O$

   d) $AgNO_3 + CaCl_2 \rightarrow AgCl + Ca(NO_3)_2$

   e) $KClO_3 \rightarrow KCl + O_2$

   f) $Cu(NO_3)_2 + Fe \rightarrow Fe(NO_3)_3 + Cu$

6. a) What is the difference between $Mg(OH)_2$ and $MgOH_2$?

   b) Does $Mg(OH)_2$ or $MgOH_2$ replace X in the balanced equation below? How can you tell?

   $X + 2HCl \rightarrow 2H_2O + MgCl_2$

7. A white solid is heated in a crucible over a flame. Oxygen gas is released and potassium chloride remains in the crucible. What elements were in the white solid? Explain your reasoning.

8. A metal is added to a solution. Lead chloride crystals precipitate out of solution (form a solid) and hydrogen gas is released. What metal was added to the solution? Explain your reasoning.

9. a) Indicate which of the numbers in the following equation are *coefficients* and which are *subscripts*.

   $3H_2SO_4 + 2Al \rightarrow Al_2(SO_4)_3 + 3H_2$

   b) Which are you allowed to adjust when balancing an equation?

10. Given the incomplete equation:

    $4Fe + 3O_2 \rightarrow 2X$

    Which compound is represented by X?

    a) FeO b) Fe_2O_3 c) Fe_3O_2 d) Fe_3O_4

11. Which equation shows a conservation of mass?

    a) $Na + Cl_2 \rightarrow NaCl$ b) $Al + Br_2 \rightarrow AlBr_3$

    c) $H_2O \rightarrow H_2 + O_2$ d) $PCl_5 \rightarrow PCl_3 + Cl_2$

12. Given the equation:

    $X + Cl_2 \rightarrow C_2H_5Cl + HCl$

    Which molecule is represented by X?

    a) C_2H_4 b) C_2H_6 c) C_3H_6 d) C_3H_8