Writing and Balancing Chemical Reactions

A chemical reaction shows the reactants needed, products formed, and states symbols for all the ingredients. Chemicals must be written correctly based on ionic charge and information given in the problem. Only after that is done correctly can a chemical reaction be balanced. A balanced reaction has the same atom count on both sides, and this is required by the law of conservation of matter.

$$Ca(s) + I_2(s) \rightarrow CaI_2(s)$$

Reactants Products

To balance a reaction, use coefficients (full-sized numbers before a chemical) to get the atom count the same on the left (reactants) and right (products) side of the reaction arrow. Coefficients multiply everything that comes after them in that particular chemical. In this case, the reaction is balanced because the atom count is the same on both sides.

$$Ca(s) + I_2(s) \rightarrow CaI_2(s)$$

Atom count on left side		Atom count on right side
__1__	Ca	__1__
__2__	I	__2__

Because the atom count is already the same on both sides, no coefficients are needed to balance the reaction. The coefficients are all one (1). The reaction says that 1 atom of solid calcium reacts with 1 molecule of solid iodine to give 1 formula unit of solid calcium iodide. Equivalently, the reaction tells us that 1 mole of solid calcium reacts with 1 mole of solid iodine to give 1 mole of solid calcium iodide.

Many reactions require coefficients (or stoichiometric coefficients) to get the atom count the same on both sides. Balance this reaction:

$$Mg(s) + N_2(s) \rightarrow Mg_3N_2(s)$$

__1__	Mg	__3__
__2__	N	__2__

The magnesium count is not balanced. Add a 3 coefficient before Mg on the left side to balance the reaction.

$$3\ Mg(s) + N_2(s) \rightarrow Mg_3N_2(s)$$

__3__	Mg	__3__
__2__	N	__2__

Balance the following reaction (recall that O_2 is diatomic):

$$HgO(s) \rightarrow Hg(l) + O_2(g)$$

__1__	Hg	__1__
__1__	O	__2__

The oxygen count is too low on the left side. A 2 coefficient before HgO fixes the O count, but it causes the Hg count to be too low on the right side.

$$2\ HgO(s) \rightarrow Hg(l) + O_2(g)$$

__2__	Hg	__1__
__2__	O	__2__

A 2 coefficient before Hg on the right side fixes the Hg count, and the reaction is balanced.

$$2\ HgO(s) \rightarrow 2\ Hg(l) + O_2(g)$$

__2__	Hg	__2__
__2__	O	__2__

Balance the following reaction:

$$P_4(s) + O_2(g) \rightarrow P_2O_5(s)$$

__4__	P	__2__
__2__	O	__5__

Sometimes balancing reactions is made easier by recognizing to start by balancing an atom count with appropriate difficulty. In this example, starting in either place leads to the same answer. For one approach, find the least common multiple for oxygen between 2 (left) and 5 (right), which is 10. To implement, add a 5 coefficient to O_2 on the left and a 2 coefficient to P_2O_5 on the right. By doing so, the reaction is balanced.

$$P_4(s) + 5O_2(g) \rightarrow 2P_2O_5(s)$$

__4__	P	__4__
_10__	O	_10__

Balance the following combustion reaction. A combustion reaction combines a fuel (propane, C_3H_8) with an oxidant (O_2). Combustion of a hydrocarbon (contains only carbon and hydrogen) or a carbohydrate (carbon, hydrogen, and oxygen in a CH_2O ratio) produces carbon dioxide and water as products.

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

__3__	C	__1__
__8__	H	__2__
__2__	O	__3__

Because oxygen appears in two different chemicals in the products, it is best to start in a different place than oxygen. Start with carbon or hydrogen. Add a 3 coefficient before carbon dioxide on the right side.

$$C_3H_8(g) + O_2(g) \rightarrow 3CO_2(g) + H_2O(g)$$

__3__	C	__3__
__8__	H	__2__
__2__	O	__6__

Next, balance hydrogen. Add a 4 coefficient before water on the right side.

$$C_3H_8(g) + O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

__3__	C	__3__
__8__	H	__8__
__2__	O	_10__

The oxygen count can be fixed by adding a 5 coefficient before oxygen on the left side. Finding the correct coefficient would have been more difficult before this step. The reaction is now balanced.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

__3__	C	__3__
__8__	H	__8__
_10__	O	_10__

Balance the following combustion reaction of butane C_4H_{10}.

$$C_4H_{10}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

__4__	C	__1__
_10__	H	__2__
__2__	O	__3__

Balance carbon by adding a 4 coefficient to carbon dioxide.

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

__4__	C	__4__
_10__	H	__2__
__2__	O	__8__

Balance hydrogen by adding a 5 coefficient to water.

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

__4__	C	__4__
_10__	H	_10__
__2__	O	_13__

To balance oxygen, recognize that the least-common multiple between a 2 and a 13 is 26. To achieve this will require a 13 coefficient for oxygen and doubling the coefficients for carbon dioxide and water. Additionally, the coefficient for butane needs to be doubled.

$C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$

__4__	C	__8__
_10__	H	_20__
_26__	O	_26__

finally,

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

__8__	C	__8__
_20__	H	_20__
_26__	O	_26__

When balancing reactions with ionic compounds, it helps to balance polyatomic ions as a group when they stay together on the left and right sides of a chemical reaction.

$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow CaCO_3(s) + NaCl(aq)$

__2__	Na	__1__
__1__	CO_3	__1__
__1__	Ca	__1__
__2__	Cl	__1__

Both the sodium count and the chloride count can be fixed by placing a 2 coefficient before sodium chloride.

$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow CaCO_3(s) + 2NaCl(aq)$

__2__	Na	__2__
__1__	CO_3	__1__
__1__	Ca	__1__
__2__	Cl	__2__

Additionally, the products for ionic compounds, such as the reaction above, can be predicted by switching the cation on the reactant side with the other anion of the other cation. The anions switch places.

Try predicting the products for this reaction:

$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow$

Answer: $Na_2CO_3(aq) + CaCl_2(aq) \rightarrow NaCl(aq) + CaCO_3(s)$

In this case, the products are correctly written because the charge of the cation matches the charge of the anion. The reaction is not balanced, so follow the steps in the previous example to balance the reaction after the products are correctly written.

Balance this reaction:
$H_2SO_4(aq) + NaOH(aq) \rightarrow$

Answer: This is an acid-base reaction, and predicting the products follows the same format as for reaction with ionic compounds.

$H_2SO_4(aq) + NaOH(aq) \rightarrow NaSO_4 + HO$

The compounds as products are not properly written because they are not charge balanced. For the first product, sulfate is -2, so two +1 sodium ions are needed. The correct formula for sodium sulfate is Na_2SO_4. For the second product, H is +1 and O is -2, so the correct formula is H_2O (or water). The reaction with correctly written products appears below.

$H_2SO_4(aq) + NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

Now, the reaction can be balanced.
$H_2SO_4(aq) + NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

__1__	Na	__2__
__1__	SO_4	__1__
__3__	H	__2__
__1__	O	__1__

Fix the sodium count by adding a 2 coefficient to sodium hydroxide.
$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

__2__	Na	__2__
__1__	SO_4	__1__
__4__	H	__2__
__2__	O	__1__

The remaining challenge is to balance H and O. Both of these appear as bound atoms in H_2O. Adding a 2 coefficient to water balances the reaction.
$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

__2__	Na	__2__
__1__	SO_4	__1__
__4__	H	__4__
__2__	O	__2__

Stoichiometry
The principle of stoichiometry depends on the law of conservation of matter. It depends on the chemical reaction being properly balanced. Stoichiometry allows us to predict the amounts and masses of reactants needed and products produced by a chemical reaction.

When 155g of ammonium nitrate decomposes, what is the theoretical yield of dinitrogen oxide and water?

Step 1: Write the balanced chemical equation
Step 2: Convert the mass of reactant to moles
Step 3: Convert moles of reactant to moles of product
Step 4: Convert moles of product to grams to get the theoretical yield

Step 1:	$NH_4NO_3 \rightarrow$	N_2O +	$2H_2O$
mass, g	155	____	____
mol	___	____	____

Steps 2, 3, and 4 for N_2O

155 g NH_4NO_3	1 mol NH_4NO_3	1 mol N_2O	44.013 g N_2O
	80.043 g NH_4NO_3	1 mol NH_4NO_3	1 mol N_2O

= 85.2g N_2O (3SD) is the theoretical yield.

Steps 2, 3, and 4 for H_2O

155 g NH_4NO_3	1 mol NH_4NO_3	2 mol H_2O	18.015 g H_2O
	80.043 g NH_4NO_3	1 mol NH_4NO_3	1 mol H_2O

= 67.8g H_2O (3SD) is the theoretical yield. You can also use the Law of Conservation of Mass

The answers from each step appear in the table below.

	$NH_4NO_3 \rightarrow$	N_2O +	$2H_2O$
mass, g	155	85.2	69.8
mol	1.936	1.936	3.873

In CHEM II, we will use before, change, after (BCA) tables to track reactants and products. A BCA table for the example above appears below.

	$NH_4NO_3 \rightarrow$	N_2O +	$2H_2O$
Before, g	155	0	0
Before, mol	1.936	0	0
Change, mol	-1.936	+1.936	+3.873
After, mol	0	1.936	3.873
After, g	0	85.2	69.8

If 74.2g of N_2O were obtained by the previous experiment, what was the percent yield?

To calculate percent yield, divide the actual yield from the experiment by the theoretical yield. %yield = 74.2/85.2 * 100% = 87.1% yield.

Limiting Reactants
In some reactions, one of the reactants runs out first, and this limits the amount of product that can form. Gasoline is the limiting reagent in your car (there is plenty of oxygen).

A related question about limiting reagents is if you had 3 tops and 11 legs in order to build 3-legged stools. Which part would run out first?

Three tops (T) would require 9 legs (L) to make 3 stools (S), so the stool tops would run out first. Two legs would be left over (in excess). In chemical terms T + 3L → S.
3T * (1S/1T) = 3S or 3 tops could produce 3 stools.
11L * (1S/3L) = 3.67S or 11 legs could produce 3.67 stools.
Because the tops produce fewer stools, the tops are the limiting reactant. To determine how many legs are left over, do this calculation:
3T *(3L/1T) = 9L or 9 legs would be needed. The number of excess legs would be 11-9= 2 legs in excess.

With chemistry, we typically work in mass. We need to convert reactants to the mole to count numbers (amounts) of reactants available and the numbers (amounts) of products produced. Typically, we convert the amounts back to mass so we can use the balance.

If you mixed 5.0g of aluminum with 5.0g of oxygen, what mass of aluminum oxide would form? How much excess reactant remains?

This is a limiting reagent question. The reagent that runs out first, the limiting reagent, will produce the least product by grams or moles.
Step 1: Write the balanced chemical reaction
Step 2: Calculate moles of each reactant.
Step 3: Calculate product formed for each reactant. The limiting reactant makes the least product. Pick a single product if more than one product is formed.

Step 1: $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

5.0 g Al	1 mol Al	2 mol Al_2O_3	101.961 g Al_2O_3
	26.982 g Al	4 mol Al	1 mol Al_2O_3

= 9.4g Al_2O_3 formed (2SD).

5.0 g O_2	1 mol O_2	2 mol Al_2O_3	101.961 g Al_2O_3
	31.998 g O_2	3 mol O_2	1 mol Al_2O_3

= 11g Al_2O_3 formed (2SD).

The reactant that forms the lesser quantity of product is the limiting reactant. Aluminum is the limiting reactant because it forms only 9.4g of Al_2O_3, and this is the theoretical yield of product that forms. The other reactant, O_2, is in excess. To determine how much

O_2 remains in excess, start with the limiting reactant, Al, and calculate the mass of O_2 that would be needed.

5.0 g Al	1 mol Al	3 mol O_2	31.998 g O_2
	26.982 g Al	4 mol Al	1 mol O_2

= 4.4g O_2 needed (2SD). The mass of O2 that remains is 5.0 - 4.4 = 0.6g O_2 remains.

Here are the results from above in a BCA table:

	$4Al(s)$ +	$3O_2(g)$ →	$2Al_2O_3(s)$
B, g	5.0	5.0	0
B, mol	0.185	0.156	0
C, mol	-0.185	-0.139	+0.0927
A, mol	0	0.017	0.0927
A, g	0	0.6	9.4

Chemical Analysis

Stoichiometry can be used to analyze samples for percent composition by mass.

Chalcanthite is an impure mineral containing $CuSO_4 \cdot 5H_2O$. Determine the percentage of copper(II) sulfate pentahydrate in the mineral from these data. A 5.13g sample of chalcanthite is crushed, and the copper(II) sulfate is dissolved in water. The blue copper (II) sulfate solution is filtered and then precipitated as 0.91 copper(II) phosphate using sodium phosphate.

Step 1: Write the balanced chemical reaction.
Step 2: Convert the 0.91g of copper(II) phosphate to moles.
Step 3: Convert moles of copper(II) phosphate to moles of copper(II) sulfate.
Step 4: Convert moles of copper(II) sulfate to moles of copper(II) sulfate pentahydrate.
Step 5: Convert moles of copper(II) sulfate pentahydrate to grams.
Step 6: Determine the precent of copper(II) sulfate pentahydrate in the mineral.

Step 1: $3CuSO_4(aq) + 2Na_3PO_4(aq) \rightarrow 3Na_2SO_4(aq) + Cu_3(PO_4)_2(s)$

Steps 2-5:

0.91 g $Cu_3(PO_4)_2$	1 mol $Cu_3(PO_4)_2$	3 mol $CuSO_4$	1 mol $CuSO_4 \cdot 5H_2O$	249.683 g CuSO4·5H2O
	380.578 g $Cu_3(PO_4)_2$	1 mol $Cu_3(PO_4)_2$	1 mol $CuSO_4$	1 mol $CuSO_4 \cdot 5H_2O$

=1.79g $CuSO_4 \cdot 5H_2O$ (2SD)

Step 6: 1.79g $CuSO_4 \cdot 5H_2O$ / 5.13g sample * 100% = 35% $CuSO_4 \cdot 5H_2O$ (2SD)