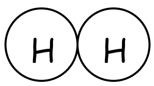
Balancing Chemical Equations

The most important point to remember when dealing with chemical equations is that the amount of an element on one side of the equation (abbreviated eqn) must equal the amount of that element on the other side of the eqn. This is true for each element involved in the reaction (abbreviated rxn). This rule is referred to as the **law of conservation of mass**. Does this eqn showing the rxn of hydrogen and oxygen to form water follow this law?

$$H_2 + O_2 \rightarrow H_2O$$

It may help you to first draw the molecules of the rxn.



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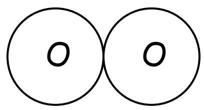

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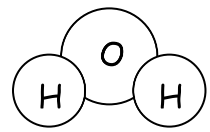


For this rxn to follow the law of conservation of mass, the amount of H must be the same at both the start and finish of the rxn. There are 2 H atoms on each side of the eqn, but what about the O? There must be the same amount of O on each side of the eqn as well. Since there are 2 O atoms at the start of the rxn and only 1 at the end, the rule isn't followed, and the eqn is unbalanced. Your job is to balance it. The first step in balancing an eqn is to make a list of how many atoms of each element are on each side of the eqn so you can keep track of what needs to be balanced.

	Start	**Finish**
H	2	2
O	2	1

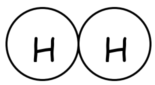
Now you can start changing the coefficients, but <u>**NEVER**</u> change the subscripts. The coefficients are the numbers in front of the molecules that tell how many of each molecule there are. When there are no coefficients in front of a molecule, it is implied that there is only one of that molecule as in the example we're using now. The subscripts are the little numbers that come after an atom as in the $_2$ in H_2O. This means that in this molecule of water, there are 2 H atoms and only 1 O atom as you can see in the picture above. You can't change any subscripts because that would change the chemical composition of a molecule, which would change the entire rxn and create something different altogether. However, you can change the coefficients, which only change the number of molecules being used in a rxn. In this example, all the coefficients are 1. Since we need more O on the right side of the eqn, maybe changing the coefficient on the H_2O to 2 would help.

$$H_2 + O_2 \rightarrow 2H_2O$$

Don't forget to revise your table as you change the coefficients.

	Start	Finish
H	2	4
O	2	2

As you can see, now we have the right number of O atoms, but too many H atoms on the right.



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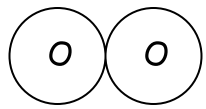

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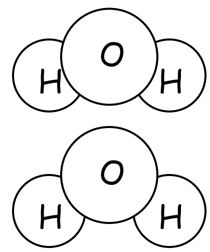


You can see that there would be 4 H atoms at the end of the rxn by drawing it or by multiplying the H's subscript by the coefficient of the whole molecule.

coefficient x subscript

$2H_2O$: 2 x 2 = 4

Now we need to adjust the number of H atoms on the left side of the eqn so it matches the right. We can do this by putting a coefficient of 2 in front of the H_2 molecule.

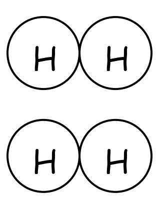
$$2H_2 + O_2 \rightarrow 2H_2O$$

coefficient x subscript

$2H_2$: 2 x 2 = 4

	Start	Finish
H	4	4
O	2	2

We now have a balanced equation.



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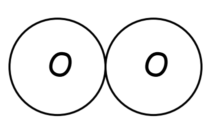

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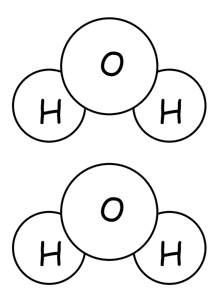
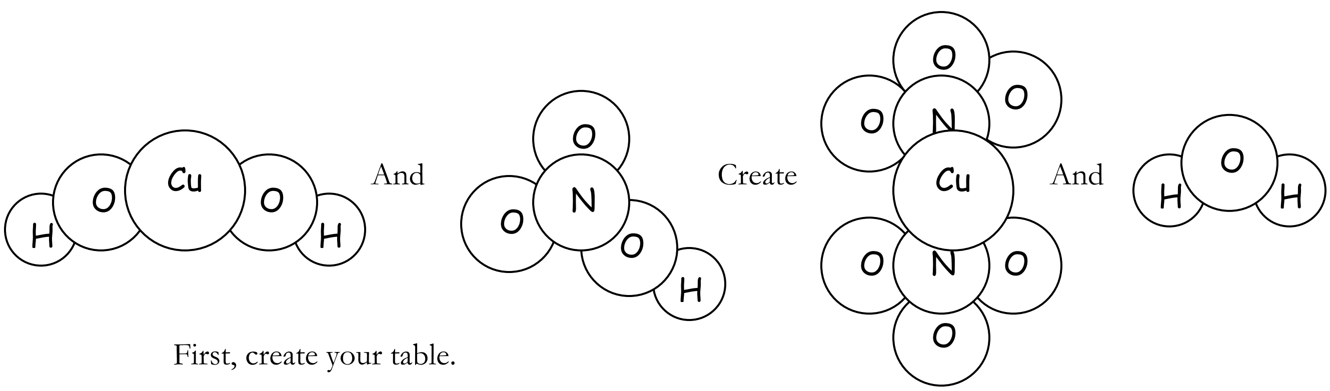


With a simpler rxn such as this one, you might be able to look at the unbalanced eqn and immediately see how you need to change the coefficients to balance it. However, some eqns are harder to balance, and you may not see how it will work out. Don't give up. Try using any coefficients that you think might help, and if they aren't working, erase your work and start again with new coefficients. Many balancing problems you'll get throughout the semester will require trial and error. For example, you might not automatically be able to see how the following eqn can be worked out.

$$Cu(OH)_2 + HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$$

The reason some of these elements are in parentheses is because they are diatomic ions, which are negatively or positively charged compounds that are made up of more than 1 element. The OH is the OH^- (hydroxide) ion, and the NO_3 is the NO_3^- (nitrate) ion. These ions are negative because they have gained a negatively charged electron thus making them more negative. They have each bonded with the positive ion Cu^{2+}, which has lost an electron thus losing negativity. This bonding of negative and positive ions has formed ionic compounds. In both ionic compounds $Cu(OH)_2$ and $Cu(NO_3)_2$, there are 2 diatomic ions indicated by the 2 outside the parenthesis. A drawing might help you see this.



First, create your table.

	Start	Finish
Cu	1	1
O	5	7
H	3	2
N	1	2

The Cu is easy to count, but with the many subscripts and parentheses, the other elements are harder to count. Since the OH in $Cu(OH)_2$ is enclosed by parentheses, the $_2$ applies to both the H and the O, so there are 2 O atoms and 2 H atoms in this molecule. Don't forget to add both the 2 O atoms from the $Cu(OH)_2$ molecule and the 3 atoms from the HNO_3 molecule together for the total number of O atoms on the left of the eqn. Now for the $Cu(NO_3)_2$ molecule, there are 2 N atoms and 6 O atoms. When you have an element with a subscript enclosed by parentheses with another subscript, multiply them together, and then multiply by the coefficient of the entire molecule.

(subscript) x subscript x coefficient
O in $Cu(NO_3)_2$: 3 x 2 x 1 = 6 O atoms

Whenever you're balancing equations, it is usually best to balance the elements that are present in the fewest molecules, and then balance the elements that are present in more molecules. Usually, H and O are present in many of the molecules and are balanced last. This is the case for this rxn. Cu and N only occur once on each side of the eqn, so balance them first. Cu is already balanced, so if possible, it would be best not to change the coefficients of the molecules that contain it. However, there is 1 N atom on the left side of the eqn and 2 on the right. Adding a coefficient of 2 to the HNO_3 molecule would balance the N.

$$Cu(OH)_2 + 2HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$$

	Start	**Finish**
Cu	1	1
O	8	7
H	4	2
N	2	2

Now balance the H and O. We need 2 more H atoms and 1 more O atom on the right. Adding a coefficient of 2 to the H_2O would balance the eqn.

	Start	**Finish**
Cu	1	1
O	8	8
H	4	4
N	2	2

$$Cu(OH)_2 + 2HNO_3 \rightarrow Cu(NO_3)_2 + 2H_2O$$

Occasionally, you may come across an eqn that will require a fractional coefficient to balance it. This often occurs when balancing combustion rxns, which are rxns of oxygen gas and a hydrocarbon (a molecule containing H and C) to form carbon dioxide gas and water vapor. The following is an example of a combustion rxn.

$$C_2H_6\ (g) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g)$$

The (g) is used to show that a molecule is in a gaseous state. (s) means the molecule is solid, (l) means it is liquid, and (aq), which is aqueous, means it is soluble in water.

	Start	Finish
C	2	1
O	2	3
H	6	2

In combustion rxns, first balance the C and H then balance the O last. In any rxn, combustion or not, it is best to revise the coefficient of the O_2 or another molecule like it such as H_2 or N_2 last. Giving CO_2 a coefficient of 2 will balance the C. Giving H_2O a coefficient of 3 so that there will be a total of 6 H atoms on the right will balance the H.

$$C_2H_6\ (g) + O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (g)$$

	Start	Finish
C	2	2
O	2	7
H	6	6

Now there are more O atoms on the right than the left, so the coefficient of O_2 needs to be balanced. There needs to be 7 O atoms on the right, but what coefficient multiplied by the subscript of 2 would give you 7 O atoms? If you can't figure it out in your head, use an algebra eqn.

$$2x = 7$$

$$\frac{2x}{2} = \frac{7}{2}$$

$$x = {}^{7}/_{2}$$

O_2 needs a coefficient of ${}^{7}/_{2}$ to balance the eqn.

$$C_2H_6\ (g) + {}^{7}/_{2}O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (g)$$

The last step is to multiply each molecule by the denominator of the fraction to make every coefficient a whole number.

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

Also, the coefficients in a balanced eqn should be the smallest whole numbers possible. For example, the coefficients of the following eqn could all be reduced by 2.

$$4NaN_3 \rightarrow 4Na + 6N_2$$

$$2NaN_3 \rightarrow 2Na + 3N_2$$

Practice Problems

1. $Na + O_2 \rightarrow Na_2O_2$
2. $Cs + N_2 \rightarrow Cs_3N$
3. $C + S_8 \rightarrow CS_2$
4. $N_2 + H_2 \rightarrow NH_3$
5. $Li + AlCl_3 \rightarrow LiCl + Al$
6. $Li + H_2O \rightarrow LiOH + H_2$
7. $Rb + P \rightarrow Rb_3P$
8. $Na + Cl_2 \rightarrow NaCl$
9. $Rb + S_8 \rightarrow Rb_2S$
10. $CH_4 + O_2 \rightarrow CO_2 + H_2O$
11. $N_2 + O_2 \rightarrow N_2O_5$
12. $Al + S_8 \rightarrow Al_2S_3$
13. $C + SO_2 \rightarrow CS_2 + CO$
14. $K + B_2O_3 \rightarrow K_2O + B$
15. $H_3PO_4 + Mg(OH)_2 \rightarrow Mg_3(PO_4)_2 + H_2O$
16. $NaOH + H_2CO_3 \rightarrow Na_2CO_3 + H_2O$
17. $Rb + RbNO_3 \rightarrow Rb_2O + N_2$
18. $Al(OH)_3 + HBr \rightarrow AlBr_3 + H_2O$
19. $NH_4OH + H_3PO_4 \rightarrow (NH_4)_3PO_4 + H_2O$
20. $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
21. $H_3PO_4 + Ca(OH)_2 \rightarrow Ca_3(PO_4)_2 + H_2O$
22. $H_3PO_4 + KOH \rightarrow K_3PO_4 + H_2O$
23. $Al(OH)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + H_2O$
24. $Ca_3(PO_4)_2 + SiO_2 + C \rightarrow CaSiO_3 + CO + P$
25. $FeS_2 + O_2 \rightarrow Fe_2O_3 + SO_2$
26. $C_6H_6 + O_2 \rightarrow CO_2 + H_2O$
27. $CH_3CH_2CH_2CH_3 + O_2 \rightarrow CO_2 + H_2O$

Solutions

1. $2Na + O_2 \rightarrow Na_2O_2$
2. $6Cs + N_2 \rightarrow 2Cs_3N$
3. $4C + S_8 \rightarrow 4CS_2$
4. $N_2 + 3H_2 \rightarrow 2NH_3$
5. $3Li + AlCl_3 \rightarrow 3LiCl + Al$
6. $2Li + 2H_2O \rightarrow 2LiOH + H_2$
7. $3Rb + P \rightarrow Rb_3P$
8. $2Na + Cl_2 \rightarrow 2NaCl$
9. $16Rb + S_8 \rightarrow 8Rb_2S$
10. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
11. $2N_2 + 5O_2 \rightarrow 2N_2O_5$
12. $16Al + 3S_8 \rightarrow 8Al_2S_3$
13. $5C + 2SO_2 \rightarrow CS_2 + 4CO$
14. $6K + B_2O_3 \rightarrow 3K_2O + 2B$
15. $2H_3PO_4 + 3Mg(OH)_2 \rightarrow Mg_3(PO_4)_2 + 6H_2O$
16. $2\ NaOH + H_2CO_3 \rightarrow Na_2CO_3 + 2\ H_2O$
17. $10Rb + 2RbNO_3 \rightarrow 6Rb_2O + N_2$
18. $Al(OH)_3 + 3HBr \rightarrow AlBr_3 + 3H_2O$
19. $3NH_4OH + H_3PO_4 \rightarrow (NH_4)_3PO_4 + 3H_2O$
20. $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
21. $2H_3PO_4 + 3Ca(OH)_2 \rightarrow Ca_3(PO_4)_2 + 6H_2O$
22. $H_3PO_4 + 3KOH \rightarrow K_3PO_4 + 3H_2O$
23. $2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O$
24. $Ca_3(PO_4)_2 + 3SiO_2 + 5C \rightarrow 3CaSiO_3 + 5CO + 2P$
25. $4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$
26. $2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
27. $2CH_3CH_2CH_2CH_3 + 13O_2 \rightarrow 8CO_2 + 10H_2O$

* Information for this handout was obtained from the following sources:

- Brown, LeMay, & Bursten. *Chemistry: The Central Science*. 9th Ed. Pearson Education, Inc. 2003.
- http://www.chemistrycoach.com/balancin.htm#Balancing%20Equations%20Worksheet