Balancing Chemical Equations – Easy Algebraic Method

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The methods of balancing chemical equations are inspection, algebraic and simplified algebraic method. For redox equations, the methods are oxidation number and half-reactions method.

Inspection is the usual method of balancing chemical equations. It is fast but it is confusing to use for an equation with many terms and the final result must be double checked to prove that the chemical equation is indeed balanced.

The algebraic method uses algebraic equations and/or matrices. This method is systematic, can be applied to difficult reactions and can be easily used with equation solvers but it is time-consuming for manual balancing of chemical equations.

The simplified or easy algebraic method works like inspection but uses algebraic expressions to represent the value coefficients and solves only a few algebraic equations. The steps of the method are as follows:

0. Put a <u>blank line</u> before each term where each coefficient will be placed.

1. Select the element (or ion) whose symbol appears only ONCE at the left side of the equation and ONCE at the right side. You may put a vertical line above the symbol to remind yourself that you have already selected that element or ion.

   a. If the selected element is already balanced, put the SAME letter coefficient at its <u>blank lines</u>.

   b. If the element is not balanced, put first the letter coefficient at the side with the GREATER number of atoms for that element, and balance the other side in terms of the same letter coefficient. For example, the letter coefficient could be "a" and the coefficient for the other side could be "2a".

   c. Repeat step 1, if needed, with another letter coefficient.

2. Fill each remaining blank line with a DIFFERENT letter coefficient or, if possible, use expressions in terms of existing letter coefficients. For example, use "2b – 2a" instead of "c". This reduces the number of required equations.

   Note: Minimize the number of coefficients but use at least TWO letter coefficients, usually a and b. Most chemical equations can be balanced using only two coefficients; some can be balanced by using up to four coefficients (a, b, c, d).

3. Write the equations for the REMAINING unbalanced elements, simplify the equations, solve for the values, and use the SMALLEST SET of whole-number coefficients.

4. Substitute the values to the letter coefficients.

Summary of steps:

1. Select the element and balance.
2. Fill the remaining blanks.
3. Solve the equation.
4. Substitute the values.

This method can also be used to balance the atoms and charges of redox equations without using oxidation numbers or half-reactions.

Challenge: solve a difficult balancing problem using the least number of coefficients.

The introduction to this method is shown in the YouTube video here.

Example Problems:

The following chemical equations are selected to illustrate the fine points of using the simplified algebraic method.

1. $AsCl_3 + NaBH_4$ --> $AsH_3 + NaCl + BCl_3$
2. $Cu + HNO_3$ --> $Cu(NO_3)_2 + NO + H_2O$
3. $Ca_3(PO_4)_2 + SiO_2 + C$ --> $CaSiO_3 + CO + P$
4. $CuSCN + KIO_3 + HCl$ --> $CuSO_4 + KCl + HCN + ICl + H_2O$
5. $CH_3ONa + NaClO_2 + HCl$ --> $COCl_2 + NaCl + H_2O$
6. $KIO_3 + KI + H_2SO_4$ --> $K_2SO_4 + H_2O + I_2$
7. $MnSO_4 + NaBiO_3 + H_2SO_4$ --> $NaMnO_4 + Bi_2(SO_4)_3 + H_2O + Na_2SO_4$
8. $[Cr(N_2H_4CO)_6]_4$ $[Cr(CN)_6]_3 + KMnO_4 + H_2SO_4$ --> $K_2Cr_2O_7 + MnSO_4 + CO_2 + KNO_3 + K_2SO_4 + H_2O$

Solutions:

1. ___$AsCl_3$ + ___$NaBH_4$ --> ___AsH_3 + ___$NaCl$ + ___BCl_3

   The first element to be balanced is As and we put "a" at the 1st and 3rd blank lines. (Fine point: it may be helpful to put a vertical line above the symbol to remind yourself that you have already balanced that element or ion.)

   Next is Na and we put "b" at the 2nd and 4th blank lines. We have one more blank line but since B already has the coefficient of "b" at the 2nd blank line, we will also put "b" at the last blank line to balance that element. (Fine point: look for the possibility of using expressions of existing coefficients to fill up the remaining blank lines instead of using new letter coefficients.)

   The following elements are balanced: As, Na and B. The chemical equation with coefficients is

   _a_ $AsCl_3$ + _b_ $NaBH_4$ --> _a_ AsH_3 + _b_ $NaCl$ + _b_ BCl_3.

   We will now write the equation for the remaining unbalanced element. We have two options: write the equation for Cl or H. We choose H since it appears only once at the left and right side of the reaction. (Fine point: write the equation for the unbalanced element or ion with the least number of symbols in the reaction.)

   The equation for H is

   $4b = 3a$, then $a = 4$ and $b = 3$.

   The balanced equation is

   $4AsCl_3 + 3NaBH_4$ --> $4AsH_3 + 3NaCl + 3BCl_3$.

2. ___Cu + ___HNO_3 --> ___$Cu(NO_3)_2$ + ___NO + ___H_2O

Copper is balanced first by putting "a" at the 1st and 3rd blank lines. Next, H is balanced by putting "b" at the last blank line and "2b" at the 2nd.

For nitrogen, since there are "2b" nitrogen atoms at 2b HNO_3 (the total amount of N in the reactants) that will produce "2a" nitrogen atoms at a_$Cu(NO_3)_2$ plus an undetermined amount x at x_NO, then x must be equal to "(2b – 2a)" or

the other part = total amount – one part,

so "(2b – 2a)" must be placed at the 4th blank line and Cu, H and N are now balanced. The chemical equation with coefficients is

_a_Cu + _2b_HNO_3 --> _a_$Cu(NO_3)_2$ + _(2b-2a)_NO + _b_H_2O.

The equation for the remaining element O is

$6b = 6a + (2b – 2a) + b$, then $a = 3$ and $b = 4$.

The balanced equation is

$3Cu + 8HNO_3$ --> $3Cu(NO_3)_2 + 2NO + 4H_2O$.

3. ___$Ca_3(PO_4)_2$ + ___SiO_2 + ___C --> ___$CaSiO_3$ + ___CO + ___P

Balance Ca by putting "a" at the 1st blank line and "3a" at the 4th. Next, balance P by putting "2a" at the last blank line. Then balance Si by putting "3a" at 2nd because it is "3a" at the 4th. Finally, balance carbon by putting "b" at 3rd and 5th blank lines. Ca, P, Si and C are now balanced. The chemical equation with coefficients is

_a_$Ca_3(PO_4)_2$ + _3a_SiO_2 + _b_C --> _3a_$CaSiO_3$ + _b_CO + _2a_P

The equation for the remaining element O is

$8a + 6a = 9a + b$, then $a = 1$ and $b = 5$.

The balanced equation is

$Ca_3(PO_4)_2 + 3SiO_2 + 5C$ --> $3CaSiO_3 + 5CO + 2P$.

4. ___CuSCN + ___KIO_3 + ___HCl --> ___$CuSO_4$ + ___KCl + ___HCN + ___ICl + ___H_2O

Cu and S are balanced first by putting "a" at the 1st and 4th blank lines. Next, C and N are balanced by putting "a" at 6th, K by putting "b" at 2nd and 5th, and iodine by putting "b" at 7th. To balance Cl, put "2b" at 3rd since there are "b+b" total atoms of Cl at 5th and 7th.

Finally, the "2b" hydrogen atoms at HCl (the total amount of H in the reactants) minus the "a" hydrogen atoms in the product HCN will give the remaining amount of product hydrogen atoms in H_2O, but that coefficient should be halved due to 2 in H_2O, so put "(2b – a)/2" at the last blank line to balance hydrogen. Cu, S, C, N, K, I, Cl and H are now balanced. The chemical equation with coefficients is

_a_CuSCN + _b_KIO_3 + _2b_HCl -->
_a_$CuSO_4$ + _b_KCl + _a_HCN + _b_ICl + _(2b-a)/2_H_2O

The equation for O is

$3b = 4a + (2b – a)/2$

$6b = 8a + 2b – a$, then $a = 4$ and $b = 7$.

The balanced equation is

$4CuSCN + 7KIO_3 + 14HCl \rightarrow 4CuSO_4 + 7KCl + 4HCN + 7ICl + 5H_2O$.

5. ___CH_3ONa + ___$NaClO_2$ + ___HCl --> ___$COCl_2$ + ___NaCl + ___H_2O

Balance carbon by putting "a" at the 1st and 4th blank lines. Next, balance Na by putting "b" at 2nd and "(a+b)" at 5th, and Cl by putting "3a" at 3rd (there are "2a + a + b" chlorine atoms in the reaction products $COCl_2$ and NaCl, and there are "b" chlorine atoms in the reactant $NaClO_2$, so the remaining coefficient must be "2a + a" or "3a").

Balance O by putting "2b" at the last blank line (there are "a + 2b" oxygen atoms in the reactants CH_3ONa and $NaClO_2$, and there are "a" oxygen atoms in the product $COCl_2$, so the missing coefficient must be "2b"). C, Na, Cl and O are now balanced. The chemical equation with coefficients is

_a_CH_3ONa + _b_$NaClO_2$ + _3a_HCl --> _a_$COCl_2$ + _(a+b)_NaCl + _2b_H_2O

The equation for H is

$3a + 3a = 4b$, simplify to get $6a = 4b$,
divide by 2 to get the smallest set of coefficients, $3a = 2b$, then $a = 2$ and $b = 3$.

The balanced equation is

$2CH_3ONa + 3NaClO_2 + 6HCl \rightarrow 2COCl_2 + 5NaCl + 6H_2O$.

6. ___KIO_3 + ___KI + ___H_2SO_4 --> ___K_2SO_4 + ___H_2O + ___I_2

Hydrogen is balanced by putting "a" at the 3rd and 5th blank lines. Next, S is balanced by putting "a" at 4th. Put "b" at 1st and, to balance K, put "(2a-b)" at 2nd (there are "2a" potassium atoms in the reaction product K_2SO_4 and there are "b" potassium atoms in the reactant KIO_3, so the missing coefficient for the reactant KI must be "(2a-b)").

Finally, put "a" at the last blank line to balance iodine. H, S, I, and K are now balanced. The chemical equation with coefficients is

_b_KIO_3 + _(2a-b)_KI + _a_H_2SO_4 --> _a_K_2SO_4 + _a_H_2O + _a_I_2

The equation for O is

$3b + 4a = 4a + a$, then $a = 3$ and $b = 1$.

The balanced equation is

$KIO_3 + 5KI + 3H_2SO_4 \text{-->} 3K_2SO_4 + 3H_2O + 3I_2$.

7. ___$MnSO_4$ + ___$NaBiO_3$ + ___H_2SO_4 --> ___$NaMnO_4$ + ___$Bi_2(SO_4)_3$ + ___H_2O + ___Na_2SO_4

Balance Mn by putting "a" at the 1st and 4th blank lines. Next, balance Bi by putting "b" at 5th and "2b" at 2nd. Then balance Na by putting "(2b-a)/2" at the last blank line (similar logic to prob. 4).

Finally, balance S by putting "(2b-a)/2 +3b –a" at 3rd (S at H_2SO_4 = S at Na_2SO_4 + S at $Bi_2(SO_4)_3$ – S at $MnSO_4$) and also at 6th to balance H. Mn, Bi, Na, S and H are now balanced. The chemical equation with coefficients is

_a_ $MnSO_4$ + _2b_ $NaBiO_3$ + _(2b-a)/2 + 3b - a_ H_2SO_4 -->
_a_ $NaMnO_4$ + _b_ $Bi_2(SO_4)_3$ + _(2b-a)/2 + 3b - a_ H_2O + _(2b-a)/2_ Na_2SO_4

The equation for O is

$4a + 6b + 4[(2b-a)/2 + 3b – a] = 4a + 12b + [(2b-a)/2 + 3b – a] + 4b – 2a$,

then $a = 4$ and $b = 5$.

The balanced equation is

$4MnSO_4 + 10NaBiO_3 + 14H_2SO_4 \text{-->} 4NaMnO_4 + 5Bi_2(SO_4)_3 + 14H_2O + 3Na_2SO_4$.

8. ___$[Cr(N_2H_4CO)_6]_4$ $[Cr(CN)_6]_3$ + ___$KMnO_4$ + ___H_2SO_4 --> ___$K_2Cr_2O_7$ + ___$MnSO_4$ + ___CO_2 + ___KNO_3 + ___K_2SO_4 + ___H_2O

This is an excellent test case of how to use the simplified method to solve a really hard balancing problem. To get you started, the coefficients are 2a, b, (b+c), 7a, b, 84a, 132a, c and (96a+b+c). Only two algebraic equations are needed to get a = 5, b = 1176 and c = 223.