

2.13: Balancing Chemical Equations

We have now determined symbols and formulas for all the ingredients of chemical equations, but one important step remains. We must be sure that the law of conservation of mass is obeyed. *The same number of atoms (or moles of atoms) of a given type must appear on each side of the equation.* This reflects our belief in Dalton's third postulate that atoms are neither created, destroyed, nor changed from one kind to another during a chemical process. When the law of conservation of mass is obeyed, the equation is said to be *balanced*.

The same number of atoms (or moles of atoms) of a given type must appear on each side of the equation.



As a simple example of how to balance an equation, let us take the reaction which occurs when a large excess of mercury combines with bromine. The video above shows the liquid bromine (a dark brown) being combined with the shiny silver (also liquid) Mercury. In this case the product is a white solid which does not melt but instead changes to a gas when heated above 345°C. It is insoluble in water and turns a salmon color in the presence of UV light. From these properties it can be identified as mercurous bromide, Hg_2Br_2 . The equation for the reaction would look like this:



but it is not balanced because there are 2 mercury atoms (in Hg_2Br_2) on the right side of the equation and only 1 on the left.

An incorrect way of obtaining a balanced equation is to change this to



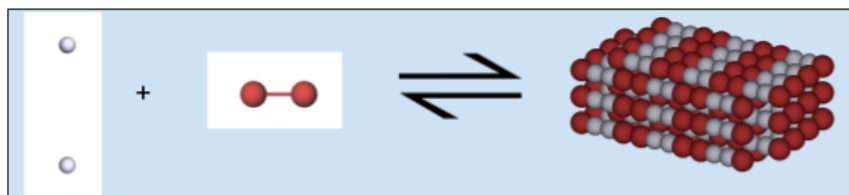
This equation is wrong because we had already determined from the properties of the product that the product was Hg_2Br_2 . Equation 2.13.2 is balanced, but it refers to a different reaction which produces a different product. The equation might also be incorrectly written as



The formula Hg_2 suggests that molecules containing 2 mercury atoms each were involved, but our previous microscopic experience with this element indicates that such molecules do not occur.

In balancing an equation you must remember that the *subscripts* in the formulas have been determined *experimentally*. Changing them indicates a change in the nature of the reactants or products. It is permissible, however, to change the amounts of reactants or products involved. For example, the equation in question is correctly balanced as follows:





A chemical equation is expressed in terms of its atomic view. 2 white spheres reacts with 2 bonded red spheres. A double sided arrow points to a regular lattice structure of bonded red and white spheres.

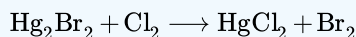
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The 2 written before the symbol Hg is called a **coefficient**. It indicates that on the microscopic level 2Hg atoms are required to react with the molecule. On a macroscopic scale the coefficient 2 means that 2 mol Hg atoms are required to react with 1 mol Br₂ molecules. Notice as well that Br₂ has a coefficient of 1, meaning that on a microscopic level, 1 molecule of Br₂ reacts with every 2 atoms of Hg, and on a macroscopic level, 1 mole of Br₂ is required for every 2 moles of Hg. Finally, on the microscopic level, 1 molecule of Hg₂Br₂ can be thought of as a single unit in the lattice structure shown above. On a macroscopic level, 1 mole of Hg₂Br₂ is 6.02 x 10²³ molecules of Mercury (I) Bromide arranged in the lattice structure shown above.

To summarize: Once the formulas (subscripts) have been determined, *an equation is balanced by adjusting coefficients*. Nothing else may be changed.

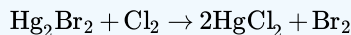
✓ Example 2.13.1 : Balancing Equations

Balance the equation

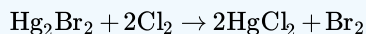


Solution:

Although Br and Cl are balanced, Hg is not. A coefficient of 2 with HgCl₂ is needed:



Now Cl is not balanced. We need 2 Cl₂ molecules on the left:



We now have 2Hg atoms, 2Br atoms, and 4Cl atoms on each side, and so balancing is complete.

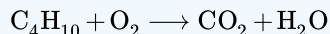
Most chemists use several techniques for balancing equations.¹ For example, it helps to know which element you should balance first. When each chemical symbol appears in a single formula on each side of the equation (as Example 2.13.1), you can start wherever you want and the process will work. When a symbol appears in three or more formulas, however, that particular element will be more difficult to balance and should usually be left until last.

¹Laurence E. Strong, Balancing Chemical Equations, *Chemistry*, vol. 47, no. 1, pp. 13-16, January 1974, discusses some techniques in more detail.

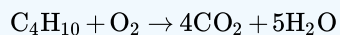
✓ Example 2.13.2 : Reaction Equation

When butane (C₄H₁₀) is burned in oxygen gas (O₂), the only products are carbon dioxide(CO₂) and water. Write a balanced equation to describe this reaction.

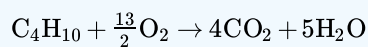
Solution First write an unbalanced equation showing the correct formulas of all the reactants and products:



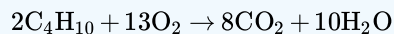
We note that O atoms appear in three formulas, one on the left and two on the right. Therefore we balance C and H first. The formula C₄H₁₀ determines how many C and H atoms must remain after the reaction, and so we write coefficients of 4 for CO₂ and 5 for H₂O:



We now have a total of 13 O atoms on the right-hand side, and the equation can be balanced by using a coefficient of $\frac{13}{2}$ in front of O_2 :



Usually it is preferable to remove fractional coefficients since they might be interpreted to mean a fraction of a molecule. (One-half of an O_2 molecule would be an O atom, which has quite different chemical reactivity.) Therefore we multiply all coefficients on both sides of the equation by two to obtain the final result:

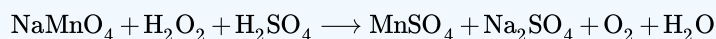


(Sometimes, when we are interested in moles rather than individual molecules, it may be useful to omit this last step. Obviously the idea of half a mole of O_2 molecules, that is, 3.011×10^{23} molecules, is much more tenable than the idea of half a molecule.)

Another useful technique is illustrated in Example 2.13.2 When an element (such as O_2) appears by itself, it is usually best to choose its coefficient last. Furthermore, groups such as NO_3 , SO_4 , etc., often remain unchanged in a reaction and can be treated as if they consisted of a single atom. When such a group of atoms is enclosed in parentheses followed by a subscript, the subscript applies to all of them. That is, the formula involves $Ca(NO_3)_2$ involves 1Ca, 2N and $2 \times 3 = 6$ O atoms.

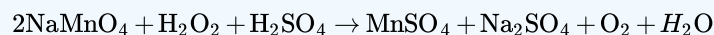
✓ Example 2.13.3 : Balancing Equations

Balance the equation

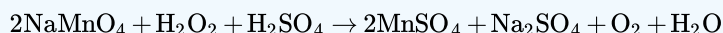


Solution

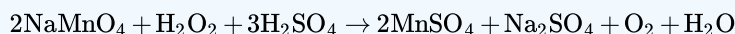
We note that oxygen atoms are found in every one of the seven formulas in the equation, making it especially hard to balance. However, Na appears only in two formulas:



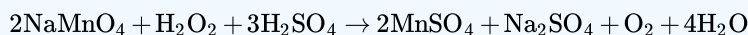
as does manganese, Mn:



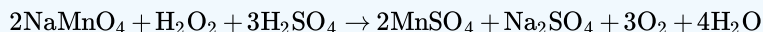
We now note that the element S always appears with 4 O atoms, and so we balance the SO_4 groups:



Now we are in a position to balance hydrogen:



and finally oxygen. (We are aided by the fact that it appears as the element.)



Notice that in this example we followed the rule of balancing first those elements whose symbols appeared in the smallest number of formulas: Na and Mn in two each, S (or SO_4) and H in three each, and finally O. Even using this rule, however, equations in which one or more elements appear in four or more formulas are difficult to balance without some additional techniques which we will develop when we investigate [reactions in aqueous solutions](#).

The balancing of chemical equations has an important environmental message for us. If atoms are conserved in a chemical reaction, then we cannot get rid of them. In other words *we cannot throw anything away*. There are only two things we can do with atoms: Move them from place to place or from compound to compound. Thus when we "dispose" of something by burning it, dumping it, or washing it down the sink, we have not really gotten rid of it at all. The atoms which constituted it are still around someplace, and it is just as well to know where they are and what kind of molecule they are in. Discarded atoms in places where we do not want them and in undesirable molecules are known as pollution.

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