Chemical Formulas

In chemistry, substances are represented by their chemical formulas because it often provides more information than the name would. In equations, these formulas help to demonstrate how the molecules are formed and the proportions of elements used to form the molecules. This worksheet will help you to understand what information chemical formulas can give you.

Let's look at a common type of reaction, a combustion reaction. This is the reaction that happens when we burn natural gas:

$$\underset{\text{methane}}{CH_4} + \underset{\text{oxygen}}{2\,O_2} \rightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{2\,H_2O}$$

Consider the second term of the reaction, 2 O_2. Each of those 2's tells you a different thing about the oxygen in the reaction. The small 2 below the O is a subscript, and its job is to indicate that every oxygen molecule participating in this reaction contains 2 oxygen *atoms*. This number cannot change easily or readily, except by some other chemical reaction. If you have a different subscript you have an entirely different chemical. The large 2 in front of the O is called a **coefficient**. This number tells you that every time this reaction happens, 2 oxygen *molecules* are involved. Of course, billions of molecules are actually involved when you turn on your natural gas stove, but they react in the ratio of one methane molecule to two oxygen gas molecules.

To determine what coefficients should be used in an equation, we must **balance** the equation. It's a kind of chemical accounting; since the atoms in a reaction cannot be destroyed, all the atoms that were there before a reaction must be there after the reaction, even if they are now part of some other molecule. One simple method for balancing an equation is to balance one element at a time and "lock" the chemicals involved together. The order in which you choose those elements is critical. The guidelines are:

[1] If an element appears only once on each side of the equation, balance it first. If an element appears in many places on either side, save it for later.

[2] If an element appears in elemental form as a species within the reaction (H_2, Ag, O_3, S_8, …) save it until last, since that species can be manipulated most easily.

Example 1: Balance these equations:
(a) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$ (b) $Ca(OH)_2 + HNO_3 \rightarrow H_2O + Ca(NO_3)_2$

Solution: (a) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

First we pick an element to balance. According to the two guidelines we should pick oxygen last: it appears in two chemicals on the right side of the equation, and it also appears in elemental form, as O_2. We should balance everything else first.

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In the equation, carbon appears just once on each side. We'll start there. There are 4 carbon atoms on the left but only one on the right. We can balance carbon by putting a coefficient of 4 in front of CO_2 (and the reminder of a 1 in front of C_4H_{10}):

$$\underline{1}\ C_4H_{10} + O_2 \rightarrow \underline{4}\ CO_2 + H_2O$$

Those two chemicals are now "locked", since they're keeping carbon balanced. If we must change one later, we'll have to change all locked chemicals the same way. Since we're saving oxygen until the end, we'll look at hydrogen next. There are 10 hydrogen atoms on the left and 2 on the right. We balance hydrogen by multiplying H_2O by 5:

$$\underline{1}\ C_4H_{10} + O_2 \rightarrow \underline{4}\ CO_2 + \underline{5}\ H_2O$$

Now notice everything but O_2 is locked together. We can change the coefficient on O_2 without changing the balance of any other element. There are 2 oxygen atoms on the left and 13 on the right (there are 4 molecules of CO_2 which have 2 oxygen atoms each: $4 \times 2 = 8$, and 5 molecules of water with 1 oxygen atom each: $5 \times 1 = 5$, for a total of $8 + 5 = 13$). The lowest common multiple of 2 and 13 is 26. We multiply O_2 by 13 and we multiply all the locked chemicals by 2; if we only changed the chemicals that contain oxygen, we'd undo the work we did balancing carbon and hydrogen. The equation now looks like:

$$\underline{2}\ C_4H_{10} + \underline{13}\ O_2 \rightarrow \underline{8}\ CO_2 + \underline{10}\ H_2O$$

It's now balanced with 8 C atoms, 20 H atoms and 26 O atoms on each side.

(b) $Ca(OH)_2 + HNO_3 \rightarrow H_2O + Ca(NO_3)_2$

The parts of the chemicals that are in brackets are polyatomic ions; the subscript tells us that a polyatomic ion is repeated that many times. $Ca(NO_3)_2$ has two NO_3^- ions, which means it has 2 nitrogen atoms and 6 oxygen atoms, total. Here, hydrogen appears in two chemicals on the left side, and oxygen appears in two chemicals on each side, so we'll do those last. If we look at calcium first, it's already balanced—there's 1 calcium atom on each side. Lock the chemicals with calcium:

$$\underline{1}\ Ca(OH)_2 + HNO_3 \rightarrow H_2O + \underline{1}\ Ca(NO_3)_2$$

There is 1 nitrogen atom on the left and 2 on the right. Add a 2 in front of HNO_3 to balance nitrogen, and lock it with the others:

$$\underline{1}\ Ca(OH)_2 + \underline{2}\ HNO_3 \rightarrow H_2O + \underline{1}\ Ca(NO_3)_2$$

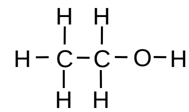
Water is the only chemical left unlocked. We'll balance hydrogen, since water is the only chemical with hydrogen on the right. When that's done, oxygen should balance itself. There are 4 hydrogen atoms on the left ($1 \times 2 + 2 \times 1 = 4$) and 2 on the left. Add a coefficient of 2 on water:

$$\underline{1}\ Ca(OH)_2 + \underline{2}\ HNO_3 \rightarrow \underline{2}\ H_2O + \underline{1}\ Ca(NO_3)_2$$

Check oxygen: there are 8 oxygen atoms on each side ($1 \times 2 + 2 \times 3 = 2 \times 1 + 1 \times 6$). It's balanced, so we're almost done. We don't show coefficients of 1, so:

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

Many chemical formulas also tell you something about the molecular structure. In complicated organic compounds, there are many ways to put the atoms together, so specifying the order you see them in the molecule is helpful. Ethanol, the chemical in liquor and beer that gets people drunk, could be written as C_2H_6O, but that doesn't tell you how the molecule goes together. However CH_3CH_2OH gives you a better idea: carbon atoms appear in a line in these kinds of molecules with the other atoms surrounding them. It looks like this:



Others, like $Ca(NO_3)_2$, do the same thing. This compound is made up of two types of ions: a calcium cation and two nitrate anions. In solid form and in solution, each nitrate ion stays together as one unit. By using the brackets we emphasize this. We find the proportion of each ion within an ionic compound by swapping charges and reducing.

Example 2: Write the chemical formulas for the following compounds: (a) barium chloride (b) calcium carbonate (c) copper (II) phosphate

Solution: (a) barium chloride: In the list of ions below, barium is Ba^{2+} and chloride is $C\ell^-$ (a charge of −1). We write the ions with the positive one first, and swap the charges as subscripts instead: $Ba_1C\ell_2$. We don't write 1 as a subscript, so the answer is $BaC\ell_2$.

(b) calcium carbonate: Calcium is Ca^{2+}. Carbonate ends with -ate or -ite, so it's an **oxyanion**, a kind of polyatomic ion. It doesn't break up, so it has coefficients of its own. Carbonate is CO_3^{2-}. We write the ions and swap the charges, but since both ions have the same magnitude of charge, we reduce it to 1 and 1: $CaCO_3$.

(c) copper (II) phosphate: There are two entries for copper: Cu^+ and Cu^{2+}. Many transition metals have two possible ions. In the name of a compound that uses one of these ions, the charge of the ion is included in brackets as a Roman numeral. This is copper (II), so we want the Cu^{2+} version of the copper ion. Phosphate is PO_4^{3-}. We write the ions and swap charges, but because we will have a new subscript on a polyatomic ion, we put it in brackets to show that it applies to the whole ion: $Cu_3(PO_4)_2$.

There's only one common positive ion that appears in other compounds: ammonium, NH_4^+. (One common positive ion, H_3O^+, occurs only in solution; there are many *uncommon* polyatomic positive ions.)

COMMON IONS positive **+** **−** negative

positive	positive	negative	negative
aluminum, $A\ell^{3+}$	chromium, Cr^{2+}, Cr^{3+}	acetate, $C_2H_3O_2^-$	bromate, BrO_3^-
ammonium, NH_4^+	cobalt, Co^{2+}, Co^{3+}	bromide, Br^-	carbonate, CO_3^{2-}
barium, Ba^{2+}	copper, Cu^+, Cu^{2+}	chloride, $C\ell^-$	chlorate, $C\ell O_3^-$
cadmium, Cd^{2+}	iron, Fe^{2+}, Fe^{3+}	cyanide, CN^-	perchlorate, $C\ell O_4^-$; chlorite, $C\ell O_2^-$;
calcium, Ca^{2+}	manganese, Mn^{2+}, Mn^{3+}	fluoride, F^-	hypochlorite, $C\ell O^-$
hydrogen, H^+	mercury, Hg^{2+} (I), Hg_2^{2+} (II)	hydride, H^-	chromate, CrO_4^{2-}
lithium, Li^+	nickel, Ni^{2+}, Ni^{3+}	hydroxide, OH^-	dichromate, $Cr_2O_7^{2-}$
magnesium, Mg^{2+}	lead, Pb^{2+}, Pb^{3+}	iodide, I^-	nitrate, NO_3^-
potassium, K^+	tin, Sn^{2+}, Sn^{4+}	nitride (azide), N^{3-}	nitrite, NO_2^-
silver, Ag^+		oxide, O^{2-}	permanganate, MnO_4^-
zinc, Zn^{2+}		peroxide, O_2^{2-}	phosphate, PO_4^{3-}
		sulphide, S^{2-}	phosphite, PO_3^{3-}
			sulphate, SO_4^{2-}
			sulphite, SO_3^{2-}

EXERCISES

A. Balance the following chemical equations:

1) $C_6H_{14} + O_2 \rightarrow CO_2 + H_2O$
2) $P + I_2 \rightarrow PI_3$
3) $H_2 + N_2 \rightarrow NH_3$
4) $P_4O_{10} + H_2O \rightarrow H_3PO_4$
5) $NH_3 + O_2 \rightarrow NO + H_2O$
6) $H_3PO_4 + KOH \rightarrow K_3PO_4 + H_2O$

B. Write the chemical formulas for the following compounds:

1) hydrogen sulphide
2) cadmium fluoride
3) potassium iodide
4) magnesium oxide
5) lithium dichromate
6) lead (II) nitrite
7) tin (IV) chloride
8) iron (III) hydroxide
9) zinc acetate
10) ammonium sulphite

C. Write the names for the following compounds:

1) KF
2) CdI_2
3) NH_4Br
4) $BaSO_4$
5) $Zn(CN)_2$
6) $Cu(NO_3)_2$
7) $AgC\ell O_4$
8) $PbCO_3$

D. Each of the chemical formulas below is correctly balanced for charge. Determine the formula and charge of the "uncommon" ion underline in the chemical's name:

1) sodium <u>bicarbonate</u>, $NaHCO_3$
2) lithium <u>oxalate</u>, $Li_2C_2O_4$
3) <u>gallium</u> hydroxide, $Ga(OH)_3$
4) <u>uranyl</u> chloride, $UO_2C\ell_2$
5) calcium <u>tungstate</u>, $CaWO_4$
6) barium <u>iodate</u>, $Ba(IO_3)_2$
7) magnesium <u>thiosulphate</u>, MgS_2O_3
8) thallium (I) <u>vanadate</u>, $T\ell VO_3$

SOLUTIONS

A. (1) $2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$ (2) $2\ P + 3\ I_2 \rightarrow 2\ PI_3$
(3) $3\ H_2 + N_2 \rightarrow 2\ NH_3$ (4) $P_4O_{10} + 6\ H_2O \rightarrow 4\ H_3PO_4$
(5) $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$ (6) $H_3PO_4 + 3\ KOH \rightarrow K_3PO_4 + 3\ H_2O$

B. (1) H_2S (2) CdF_2 (3) KI (4) MgO (5) $Li_2Cr_2O_7$ (6) $Pb(NO_2)_2$ (7) $SnC\ell_4$
(8) $Fe(OH)_3$ (9) $Zn(C_2H_3O_2)_2$ (10) $(NH_4)_2SO_3$

C. (1) potassium fluoride (2) cadmium iodide (3) ammonium bromide
(4) barium sulphate (5) zinc cyanide (6) copper (II) nitrate (7) silver perchlorate
(8) lead (II) carbonate

D. (1) HCO_3^- (2) $C_2O_4^{2-}$ (3) Ga^{3+} (4) UO_2^{2+} (5) WO_4^{2-} (6) IO_3^- (7) $S_2O_3^{2-}$ (8) VO_3^-