Determining Neutral Chemical Formulas for Ionic Compounds

What is an ionic compound? An ionic compound is a compound that has a positive charged ion (cation) and a negative ion (anion). The two ions are held together by the electrostatic force of the attraction of opposite charges.

What kinds of atoms form ionic compounds? In general, an ionic compound is formed when a metal atom combines with a non-metal atom. The metal has a weak hold on its valence electrons (outside electrons) so it readily gives them to the non-metal atom. This means the metal ion becomes positively charged (fewer electrons than protons) and the non-metal atom becomes negatively charged (more electrons than protons). Any time you see a metal atom with a non-metal atom that is an ionic compound.

How is an ionic compound written? By convention, chemists write the positive ion first, and the negative ion second. This means the metal is written first, and then the non-metal.

What is a poly-atomic ion? Poly-atomic means "many-atoms" . A poly-atomic ion is a group of non-metal atoms that all work together to form a single ion. The non-metal atoms are bonded together, and the charge on the poly-atomic ion is for the overall group. Most poly-atomic ions are negatively charged (anions). Your lecture instructor will give you a list of any poly-atomic ions you are expected to know. Common examples include hydroxide, OH^{-1} and sulfate SO_4^{-2}. A few polyatomic ions are positively charged, most common is ammonium NH_4^{+1}. Any compound that contains a poly-atomic ion is by definition an ionic compound, even if there is no metal atom present. For example, ammonium hydroxide, NH_4OH is an ionic compound.

What is a neutral formula for an ionic compound? All ionic compounds must be neutral in terms of electrical charge. This means that overall, the compound must be neutral. This requires that the total amount of positive charge is equal to the total amount of negative charge.

How do you write a neutral formula for an ionic compound? The process for doing this can be summarized by the following steps (depending on what information you have, you may not need to start at #1, you may skip to #2).

1. Determine the charges on the ions in the compound.

The conceptual way: Look at the atoms that make up the compound.

Identify the metal atom, and determine the number of electrons in the metal's atoms outer shell. The metal will need to lose this number of electrons. For example, Na has 1 electron in the outer shell, so it makes a +1 ion, Na^{+1}. Aluminum has 3 electrons in the outer shell, so it would make a +3 ion, Al^{+3} . [Note this will only work for main-group metal elements, in columns 1,2,and 13. You need a more sophisticated model of the atom to predict ions in the transition metals, group 3-12. This is beyond the scope of this class.]

Identify the non-metal atom. Determine the number of electrons in the atom's outer shell. Subtract this number from 8 to determine the number of electrons that the non-metal will gain. For example: Cl has 7 valence electrons. 8-7, = 1 so chlorine needs to gain one electron, it makes a –1 ion, Cl^{-1}. S has six valence electrons, so it needs to gain 2 and makes a –2 ion, S^{-2}. Notice that Ne has 8 valence electrons, so it wouldn't gain any, which means it won't make an ion, and will not form an ionic compound.

The memorization way: Look at the atoms that make up the compound.

For the metals, any metal in group 1 (or 1A) will always form a +1 ion, for group 2 (or 2A) the metals will always form a +2 ion, and for group 13 (3A) the metals will always form a +3 ion. Special note, B is not a metal, so it does not form a +3 ion.

For the non-metals, any non-metal in group 18 (8A) will not form ions, for group 17 (7A) they will form –1 ions, for group 16 (6A) they will form –2 ions, for group 15 (5A) they will form –3 ions. Special note: pay attention to which atoms are metals and which are non-metals in group 16,15. Elements in group 14 do not usually form ions so are not included here.

IF YOU HAVE A POLY-ATOMIC ION, the charge is given with the ion formula.

2. Now you have to equal numbers of positive and negative charge using subscripts.

The criss-cross method: To write the compound, for each ion you put the subscript that is equal the amount of charge on the opposite ion. Remember chemists don't write the subscript if it one. For example

Na^{+1} ~~and Cl^{-1}~~ = NaCl

Mg^{+2} ~~and Cl^{-1}~~ = $MgCl_2$

Special Note: If the subscripts are divisible by a common factor, you use the lowest ratio. For example:

Mg^{+2} ~~and O^{-2}~~ = Mg_2O_2 = really MgO

(all subscripts divisible by 2)

More Examples:

Cation	Anion	Neutral compound
Be^{+2}	S^{-2}	BeS
Al^{+3}	P^{-3}	AlP
Na^{+1}	O^{-2}	Na_2O
Mg^{+2}	N^{-3}	Mg_3N_2
Al^{+3}	S^{-2}	Al_2S_3

FOR POLY-ATOMIC Ions: This method works exactly the same. The only additional information that you need is that you need to put the polyatomic in ( ) if the subscript is anything other than 1. You do not need ( ) if the subscript is 1.

Cation	Anion	Neutral compound
Be^{+2}	SO_4^{-2}	$BeSO_4$
Al^{+3}	PO_4^{-3}	$AlPO_4$
Na^{+1}	CO_3^{-2}	Na_2CO_3
Mg^{+2}	NO_3^{-1}	$Mg(NO_3)_2$
Al^{+3}	SO_4^{-2}	$Al_2(SO_4)_3$
Ca^{+2}	OH^{-1}	$Ca(OH)_2$

The mathematical method: The sum of the positive charges and the negative charges has to be equal to zero. You can write an equation to express this:

Subscript(charge on cation) + Subscript(charge on anion) = 0.

Now suppose we were combining a Ca^{+2} ion with a F^{-1} ion. We can see that if the subscripts were both 1, the compound would not be neutral.
1 (+2) + 1(-1) = +1 not O ! This would not be neutral!

So to get them neutral, we need more negative ions. So increase that subscript from one to two, and see if that works.

Sure enough : 1 (+2) + 2(-1) = 0 so the correct formula would be CaF_2.

This method may be confusing to use when you are figuring out the subscripts, but it is a great way to check if the subscripts you choose were the correct ones. You can plug them into the equation and make sure you get zero.