Monatomic Ions

Ions are atoms that have either lost or gained electrons. While atoms are neutral, ions are **charged particles**.

- A *loss* of electrons results in a positive ion or **cation** (pronounced "cat-eye-on").
- A *gain* of electrons results in a negative ion or **anion** (pronounced "an-eye-on").

Although ions and elements have similar chemical symbols, they are entirely different substances with different physical properties.

A. Monatomic Ions

In order to determine the charge of *monatomic* ions, you can use the periodic table as a guide:

Group # (Column)	Ion Charge	Examples
1	These elements lose **one** electron to form **+1** ions.	Na^+, Li^+, K^+
2	These elements lose **two** electrons to form **+2** ions.	Mg^{2+}, Ca^{2+}, Ba^{2+}
Groups 3-12	The elements in groups 3-12 are called transition metals. These elements always lose electrons to form **positive** ions (cations) but their charges vary. For example, iron can form a +2 or a +3 ion. *In cases like these, you must be told which ion to use.*	Fe^{2+}, Fe^{3+}
13	These elements lose **three** electrons to form **+3** ion.	Al^{3+}
14	The charges on these ions vary. Carbon and silicon do not form ions. For the rest of the group, you must be given the charge.	Sn^{2+}, Pb^{2+}
15	These elements gain **three** electrons and form **–3** ions.	N^{3-}, P^{3-}
16	These elements gain **two** electrons to form **–2** ions.	O^{2-}, S^{2-}
17	These elements gain **one** electron to form **–1** ions.	F^-, Cl^-, Br^-, I^-
18	These atoms do NOT form ions. Their charge is always **zero**.	He, Ne, Ar, Kr

Naming Ions (Nomenclature):

Simple **cations** are named by saying the element and adding the word "ion."

Na^+ is called "sodium ion"
Mg^{2+} is called "magnesium ion"

Simple **anions** are named by dropping the ending off the element name and adding "ide."

F^- is called "fluoride"
O^{2-} is called "oxide"
N^{3-} is called "nitride"

Note: the charge of a monatomic **anion** is equal to the group number minus 18.

Nomenclature Worksheet 1:
Monatomic Ions

Use a periodic table to complete the table below:

Element Name	**Element Symbol**	**Ion Name**	Ion Formula
1. sodium			
2. bromine			
3. magnesium			
4. chlorine			
5. oxygen			
6. boron			
7. lithium			
8. neon			
9. phosphorus			
10. aluminum			
11. calcium			
12. iodine			
13. nitrogen			
14. cesium			
15. sulfur			
16. fluorine			
17. potassium			
18. barium			
19. hydrogen			
20. helium			

Simple Binary Ionic Compounds

Ionic compounds are compounds formed by the combination of a **cation** and a **anion**. **(Think: "metal plus nonmetal").** Ionic compounds are more commonly known as "salts." Binary ionic compounds are compounds containing only two elements, as demonstrated in the examples below.

When writing formulas for ionic compounds, we use **subscripts** to indicate how many of each atom is contained in the compound. Remember that even though ions have charges, ionic compounds must be **neutral**. Therefore, the charges on the cation and the anion must cancel each other out. In other words, the **net charge** of an ionic compound equals zero.

Example 1:

For a salt containing sodium ion, $\mathbf{Na^+}$**,** and chloride, $\mathbf{Cl^-}$, the ratio is one to one. The positive charge on the sodium ion cancels out the negative charge on the chloride.

$$(+1) + (-1) = 0$$

Therefore, the formula for the salt is **NaCl.** (The actual formula is Na_1Cl_1, but chemists omit subscripts of 1).

Example 2:

For a salt containing calcium ion, Ca^{2+}, and chloride, Cl^-, the ratio can't be one to one.

$$(+2) + (-1) = +1$$

Remember that ionic compounds must be neutral. In order to yield a neutral compound, **two** chlorides must bond to the calcium ion:

$$(+2) + 2(-1) = 0$$

So, the formula for this salt is $\mathbf{CaCl_2}$**.**

Nomenclature:

When naming ionic compounds, simply write the *element name* of the metal followed by the *ion name* of the nonmetal. **(Remember: the metal ion (cation) is always written first!)**

NaCl is called "**sodium chloride**," and $CaCl_2$ is called "**calcium chloride.**"

Nomenclature Worksheet 2:
Simple Binary Ionic Compounds

Please complete the following table:

Name of Ionic Compound	Formula of Ionic Compound
1. Sodium bromide	
2. Calcium chloride	
3. Magnesium sulfide	
4. Aluminum oxide	
5. Lithium phosphide	
6. Cesium nitride	
7. Potassium iodide	
8. Barium fluoride	
9. Rubidium nitride	
10. Barium oxide	
11.	K_2O
12.	MgI_2
13.	$AlCl_3$
14.	$CaBr_2$
15.	Na_3N
16.	LiF
17.	Ba_3P_2
18.	Cs_2S
19.	SrF_2
20.	$NaCl$

Polyatomic Ions

Polyatomic ions contain two or more different atoms (polyatomic means "many atoms"). Here are some common examples:

a. **ammonium ion, NH_4^+** (the only positive polyatomic ion you need to know)

b. **"ATE" ions:** contain an atom bonded to several oxygen atoms:

Nitrate = NO_3^- Phosphate = PO_4^{3-} Sulfate = SO_4^{2-}
Carbonate = CO_3^{2-} Acetate = $CH_3CO_2^-$ Chlorate = ClO_3^-

c. **"ITE" ions:** remove one oxygen from the "ATE" ion and keep the same charge:

Nitrite = NO_2^- Phosphite = PO_3^{3-} Sulfite = SO_3^{2-}
Chlorite = ClO_2^-

d. **Other common complex ions**:

Hydroxide = OH^- Cyanide = CN^-

Ionic Compounds Containing Polyatomic Ions

As you've already learned, ionic compounds are formed by the combination of **a positive ion** (cation) and a **negative ion** (anion). This is the same when dealing simple ions or complex ions. Be careful to note, however, that complex ions are **grouped together** and should not be separated. In other words, don't ever separate the sulfate ion, SO_4^{2-} into sulfur and oxygen. **If it's written as a group, keep it as a group!**

Since complex ions come in groups, things can get tricky when using subscripts. As a result, we use **parentheses** to separate the ion from the subscript:

If we need two sulfates in a compound, we write: $(SO_4)_2$.
If we need three nitrates in a compound, we write: $(NO_3)_3$.

And, just as before, the **net charge** of the compound must be **zero**. For a salt containing sodium ion, Na^+, and nitrate, NO_3^-, the ratio would be 1:1 since the positive and negative charges cancel out. Therefore, the formula is $NaNO_3$ and is called sodium nitrate. (Note: no parentheses are necessary here).

For a salt containing calcium ion, Ca^{2+}, and nitrate, NO_3^-, the ratio must be 1:2 (one calcium ion for every two nitrates). So, the formula would be **$Ca(NO_3)_2$.**

Nomenclature Worksheet 3:
Ionic Compounds Containing Polyatomic Ions

Please complete the following table:

Name of Ionic Compound	Formula of Ionic Compound
1. Sodium chromate	
2. Calcium carbonate	
3. Magnesium nitrate	
4. Aluminum sulfate	
5. Lithium phosphate	
6. Ammonium chloride	
7. Cesium chlorate	
8. Potassium sulfate	
9. Barium acetate	
10. Rubidium cyanide	
11.	KCH_3CO_2
12.	$Mg_3(PO_4)_2$
13.	$Al(ClO_3)_3$
14.	$CaSO_4$
15.	$Sr(HCO_3)_2$
16.	$NaNO_3$
17.	Li_2CO_3
18.	$Ba(NO_3)_2$
19.	Cs_2CrO_4
20.	NH_4OH

Ionic Compounds Containing Transition Metals

The transition metals are the elements located in the middle of the periodic table (in groups 3-12. Unlike the group 1A and 2A metal ions, the charges of transition metal ions are not easily determined by their location on the periodic table. Many of them have more than one charge (also known as an **oxidation state**). There are *eight* transition metals that you should highlight on your periodic table:

Co, Cr, Cu, Fe, Mn, Hg, Sn, and Pb

Each of these elements form **more than one** ion and therefore must be labeled accordingly. For example, iron forms two ions: $\mathbf{Fe^{2+}}$ and $\mathbf{Fe^{3+}}$**.** We call these ions "iron (II) ion" and "iron (III) ion" respectively. (See "Table of Transition Metal Ions").

When naming any ion from the elements listed above, you **MUST** include a Roman numeral in parentheses following the name of the ion. The this roman numeral is equal to the **charge** on the ion. We don't include the "+" because all metal ions are positive. Here are two more examples:

Pb^{4+} = "lead (IV) ion" Cr^{3+} = "chromium (III) ion

Similarly, when naming a **compound** containing one of these transition metals, you must include the Roman numeral as well. "Iron Chloride" isn't specific enough since the compound could contain either iron (II) or iron (III) ion. You must specify the charge on the iron.

Iron (II) chloride contains the Fe^{2+} ion. When combined with chloride, Cl^{-}, we know the formula must be $FeCl_2$.

Iron (III) chloride contains the Fe^{3+} ion. This time, three chlorides are required to form a neutral compound. Therefore, the formula is $FeCl_3$.

By looking at the formula of an ionic compound, we can determine the charge (oxidation state) of the metal.

<u>Example:</u> Write the **name** of Co_2O_3

1. Recognize that Co, cobalt, is a transition metal. This means that you must include a Roman numeral after its name. So, the basic name will be Cobalt (__) Oxide.
2. To find the charge on cobalt, use oxide as a key. Oxide has a charge of –2 so three oxides will have a charge of –6.
3. What balances a –6 charge? A +6 charge! So, the positive half of the compound must equal +6.
4. Since there are two cobalt ions, the charge is split between them. So, each one has a +3 charge. Therefore, we are using the Co^{3+} ion and the compound is called **cobalt (III) oxide.**

Remember that anions (negative ions) always have a definite charge. When dealing with compounds containing transition metals, *look to the anion first*. Determine the charge of the anion and then solve to figure out the charge of the cation.

When dealing with metals other than the transition metals, you don't need Roman numerals. In other words, calcium ion, Ca^{2+} is **always** +2. Don't call $CaCl_2$ "calcium (II) chloride." Its name is "calcium chloride."

Nomenclature Worksheet 4:
Ionic Compounds Containing Transition Metals

Please complete the following table:

Name of Ionic Compound	Formula of Ionic Compound
1. Copper (II) sulfate	
2. Copper (I) oxide	
3. Chromium (III) cyanide	
4. Cobalt (II) hydroxide	
5. Silver bromide	
6. Zinc nitrate	
7. Iron (III) acetate	
8. Lead (IV) sulfate	
9.	$FeCl_2$
10.	$PbSO_3$
11.	$Co_2(CO_3)_3$
12.	$AgNO_3$
13.	$Zn(CN)_2$
14.	$CuClO_3$
15.	$Cr(OH)_3$
16.	Hg_2O

Nomenclature Worksheet 5:
Ionic Compounds Summary

Name the following compounds:

1. CaF_2 ____________
2. Na_2O ____________
3. BaS ____________
4. $CuSO_4$ ____________
5. Fe_2O_3 ____________
6. $HgCl_2$ ____________
7. $AgNO_3$ ____________
8. $MgCO_3$ ____________
9. $KC_2H_3O_2$ ____________
10. $K_2Cr_2O_7$ ____________
11. $Al(OH)_3$ ____________
12. $PbBr_2$ ____________
13. $ZnSO_3$ ____________
14. $NaHCO_3$ ____________
15. NH_4Cl ____________
16. Li_3PO_4 ____________
17. $SnCl_2$ ____________
18. $Al(NO_2)_3$ ____________
19. Rb_2CrO_4 ____________
20. $KMnO_4$ ____________
21. $CuCl$ ____________
22. $FeSO_4$ ____________

Give the formula for each compound:

23. sodium fluoride ____________
24. potassium sulfide ____________
25. calcium carbonate ____________
26. magnesium hydroxide ____________
27. zinc nitrate ____________
28. silver acetate ____________
29. copper (II) oxide ____________
30. iron (III) chloride ____________
31. barium chromate ____________
32. aluminum oxide ____________
33. lead (II) sulfate ____________
34. tin (IV) oxalate ____________
35. calcium phosphate ____________
36. lithium permanganate ____________
37. mercury (I) nitrate ____________
38. radium sulfite ____________
39. chromium (III) chloride ____________
40. ammonium sulfide ____________
41. copper (II) acetate ____________
42. calcium bicarbonate ____________
43. tin (II) oxide ____________
44. silver sulfite ____________

Naming Binary Covalent Compounds

Binary covalent compounds come from the combination of two nonmetals (or a nonmetal and a metalloid). These compounds do not involve ions; as a result, they have a slightly different naming system. Chemists use *prefixes* to indicate the number of atoms in each compound. The prefixes are listed in the table below:

# of Atoms	Prefix
1	Mono
2	Di
3	Tri
4	Tetra
5	Penta
6	Hexa
7	Hepta
8	Octa
9	Nona
10	Deca

When naming binary covalent compounds, the first element name is given followed by the second element with an "ide" ending. The first element gets a prefix when there is more than one atom in the compound.* The second element ALWAYS gets a prefix. Here are some examples:

Compound	**Name**
NO*	Nitrogen Monoxide
N_2O	Dinitrogen Monoxide
NO_2*	Nitrogen Dioxide
N_2O_3	Dinitrogen Trioxide
N_2O_4	Dinitrogen Tetraoxide
N_2O_5	Dinitrogen Pentaoxide

* Notice that the prefix "mono" is omitted in these cases

Prefixes are necessary when naming covalent compounds because the atoms can combine in any whole number ratio. N_2O, for example, cannot simply be called "nitrogen oxide," because there are several other compounds that contain nitrogen and oxygen. We must specify that there are two nitrogen atoms bonded to a single oxygen atom.

When dealing with ionic compounds, there is only one way for a cation and anion to combine to form a neutral compound. As a result, there is no need to use prefixes. This is why $CaCl_2$ is called "calcium chloride," rather than "calcium dichloride."

Nomenclature Worksheet 6:
Binary Covalent Compounds

Please complete the following table:

Name of *Covalent* Compound	Formula of *Covalent* Compound
1. carbon dioxide	
2. phosphorus triiodide	
3. sulfur dichloride	
4. nitrogen trifluoride	
5. dioxygen difluoride	
	6. N_2F_4
	7. SCl_4
	8. ClF_3
	9. SiO_2
	10. P_4O_{10}

Determine whether the following compounds are **covalent** or **ionic** and give them their proper names.

1. $Ba(NO_3)_2$
2. CO
3. PCl_3
4. KI
5. CF_4
6. MgO
7. Cu_2S
8. SO_2
9. NCl_3
10. XeF_6

<u>Shortcut for Formula Determination:</u>

Use the following method when asked to determine the formula of an ionic compound:

1. Write the two ions with their charges (metal first).
2. Ignoring the + or – charges, "crisscross" the numbers and make them subscripts.
3. Then, rewrite the formula, dropping the charges.

(See Examples Below)

Example 1:
Write the formula for **calcium chloride**:

1. Write the two ions with their charges (metal first).

   Ca^{2+} Cl^{-}

2. Ignoring the + or – charges, "crisscross" the numbers and make them subscripts:

   Ca^{2+} Cl^{-}

3. Then, rewrite the formula, dropping the charges. In this case, the formula is: **$CaCl_2$.**

Example 2:
Write the formula for **magnesium oxide:**

1. Write the two ions with their charges (metal first).

   Mg^{2+} O^{2-}

2. Ignoring the + or – charges, "crisscross" the numbers and make them subscripts:

   Mg^{2+} O^{2-}

3. Then, rewrite the formula, dropping the charges. The rewritten formula is: Mg_2O_2.
   Note: Since the subscripts for the anion and cation are the same, the formula reduces to Mg_1O_1.

Therefore, the correct formula is written as: **MgO**.