Inorganic Nomenclature

The ability to name common chemical compounds is absolutely essential for success in a general chemistry course, and facilitates communication between chemists. While the actual process of naming compounds is not all that difficult in and of itself, there are many subtle points that must be observed in assigning the correct name. Keeping track of all these tiny details causes many students to become frustrated; however, the reality of the situation is that there is no way to avoid learning all these nuances and still be successful with this subject.

The method I am presenting here teaches nomenclature from a "questions" based perspective. You follow a series of questions on a flowchart which take you to different "points" in the naming process, indicated by large numbers and letters next to the rectangles on the chart. By following the path carefully and reading the text that is associated with each "point" you will understand how to name almost any compound you will encounter in an introductory or general chemistry course.*

`Please note that the text written in Courier font (the font this paragraph is written in) is only for reference, and to satisfy any curiosity you may have. Do not worry about memorizing any information from these sections.`

How to study nomenclature

I strongly recommend you use the following procedure to learn nomenclature. This is an area in which practice makes perfect, and a well-organized plan helps a lot, too.

1. Practice tracing your way through the flowcharts, making sure you understand how it works. If there are any questions in the diamonds that you do not completely understand, try to read through the points to see if they become more clear. If not, ask for help from an instructor as soon as possible.
2. Follow the path on the first flowchart from Start to Point 1. Read through the text for this Point. Retrace the path to Point 1, but this time read the passage for Point 1 in depth, highlighting or circling any fine points that you find especially important. Continue in this fashion for each of the points on the flowcharts.
3. Read through the explained examples, following the flowcharts along with the example and the text for the Points it pertains to.
4. Attempt the first twenty exercises on your own, using the flowchart and the text for each point as a guide. Do any additional exercises as you see fit.
5. Memorize the prefixes for binary-nonmetals in Point 2, the chemicals with common names in Point 4, the three cations in Point 10, the common names for the cations in Point 11, and the formulas and names of all polyatomic ions in Point 9(NH_4^+) and Point B. By now you should also know the charges of all Group I, II, and III cations

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* This packet does not teach students how to name inorganic coordination compounds; the nomenclature rules for these compounds are usually presented in the final semester/quarter of a General Chemistry course.

(Point 9) and all Group IV, V, VI, and VII anions (Point A.). These parts will take the longest, but if you work diligently with flashcards you should be able to learn this material in about a week's time. There is no real thinking involved here, just memorizing.

6. List the name of as many oxyanions as you can think up, using Point C as your guide. Be sure to practice changing the number of oxygen atoms in the ions. Do the same for the oxyacids in Point 13.
7. Continue to practice naming compounds, but use the following procedure: Take your time and attempt to name the compound correctly *without* looking at the flowchart. After naming the compound, trace your steps on the flowchart. Change your answer if you think it's necessary. Finally, look up the answer to check for correctness.
8. After you have thoroughly mastered all the previous steps try time-testing yourself, naming compounds as quickly as you can.

Point 1: Binary Nonmetal Compounds

Binary nonmetals are made up of atoms from *exactly* two different elements. Metalloids are also included in this category. Examples include NO_2, P_4O_{10}, and HCl. These compounds are also called *molecular compounds*, as the atoms are held together by covalent bonds, forming individual molecules. No ions are included in this class of compound, although some of these compounds may form ions when added to water (see Point 5).* The naming rules for these compounds are straightforward in all cases except for some of those which contain hydrogen. We will first consider those molecular compounds which do not contain hydrogen, and then address those that do on a situation-by-situation basis.

Important Note: Binary nonmetal compounds should have no charge on them. So, NO_2 (a neutral molecule) follows these naming rules, but NO_2^- does not. These charged species are ions, and their naming rules are described at Points 7-12.

The order which the two elements should appear is provided here, with elements which should come first listed earliest in the list. There is really no need to memorize this since the order will always be given to you in either the name or the formula itself. However, this could prove to be a useful reference when doing problems requiring you to provide correct empirical and molecular formulas.

B, Si, C, Sb, As, P, N, H, Te, Se, S, At, I, Br, Cl, O, F

For compounds containing noble gases combined with another non-metal, the noble gas always comes first (i.e. XeO_4)

* $(NH_4)_3N$, which is composed of the ammonium ion and the nitride ion, does *technically* contain exactly two types of nonmetal atoms, but it should be clear from the way the formula is written that the ionic rules apply (see Point 7).

Point 2: Binary nonmetal compounds <u>not</u> containing hydrogen

Explanation: Many combinations of atoms are possible with two different types of non-metal atoms. Consider these binary nonmetal formulas, containing nitrogen and oxygen:

N_2O NO NO_2 N_2O_5

Clearly we cannot name each of these "nitrogen oxide" because we would never be able to tell them apart without writing out the formula for each! The naming system for these compounds, <u>and only these types of compounds</u>, requires us to specify the number of each type of atom present in the molecule. This is done by adding a prefix from the table below to the name of each element:

Number of Atoms in Molecule	**Prefix**
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

There are a few minor details that must also be observed as well.

Procedure: First, add a prefix (from the table) to the name of the first element in the compound to indicate how many of that type of atom are indicated in the formula. Do the same for the second element, but change its ending (usually, *but not always*, the last syllable) to "-ide" (chlorine becomes chloride, selenium becomes selenide, oxygen becomes oxide, hydrogen becomes hydride, etc.).

<u>Example:</u> N_2O_3

There are two nitrogen atoms in the formula, so we start with "dinitrogen" as the first part of the name. There are three oxygen atoms in the formula, so we add on "trioxide." The correct name is "dinitrogen trioxide."

There are two changes that are generally made to this procedure that you must know:

1. Never use the prefix "mono-" with the first element; it is understood.

So, CO_2 is "carbon dioxide", *not* "monocarbon dioxide."

2. If adding the prefix causes either the combination of "oo" or "ao" to occur in the name, drop the first of these vowels. It sounds awkward if you do not.

N_2O seems to be "dinitrogen mon<u>oo</u>xide", but you should drop the first "o"; the correct name is "dinitrogen monoxide."

P_2O_5 is *not* named "diphosphorus pent<u>ao</u>xide"; it is correctly called "diphosphorus pentoxide."

Point 3: Organic compounds

Organic compounds have their own naming rules which depend on the structure of the molecule being considered. For example, two distinct compounds, cyclopropane and propene, both have the formula C_3H_6. We will not consider organic nomenclature here with the following exceptions:

> You should know that CH_4 is called "methane."
> You may want to know that C_2H_6 is called "ethane."
> You may want to know that C_3H_8 is called "propane."

Point 4: Binary compounds with common names

Some binary non-metals containing hydrogen have common names that are virtually always used and should be memorized.

> You must know that H_2O is always called "water."
> You must know that NH_3 is always called "ammonia."
> You should know that PH_3 is called "phosphine."

One other compound, H_2O_2, could have brought you to this point also. It is called "hydrogen peroxide." You may occasionally encounter the peroxide ion, O_2^{2-}, in naming ionic compounds.

Many other hydrogen containing compounds also have common names that you may encounter at some point, such as arsine (AsH_3), stibine (SbH_3), and silane (SiH_4). Boranes—compounds containing boron and hydrogen—also have common names, such as diborane for B_2H_6. Other common names for chemicals (many named for those who first synthesized them) will come up throughout your study of chemistry; be sure to ask your instructor which ones you will be expected to know.

Point 5: Acids of monatomic anions

When added to water to make an aqueous solution, some hydrogen-containing binary nonmetals split into ions, forming solutions classified as acids.

Procedure: . The name of the acid is based on the element hydrogen is attached to. Add the prefix "hydro-" to the name of the element, and change the ending to "-ic acid".

Examples: HCl(*aq*) is called hydrochloric acid.
HBr(*aq*) is called hydrobromic acid.
HI(*aq*) is called hydroiodic acid (some call it hydriodic acid—that double vowel thing again!)

Exception: With H_2S(*aq*), do not drop the ending on "sulfur". The correct name is "hydrosulfuric acid".

Point 6: Hydrogen-containing binary nonmetals

These compounds basically follow the procedure set down in Point 2 except that you generally do not include the prefixes in the name.

Procedure: The first part of the name is just "hydrogen." Change the ending of the second element to "-ide" (as if it were an anion: see point 12).

Examples: $HCl(g)$ is called hydrogen chloride.
$H_2S(g)$ is called hydrogen sulfide.

Point 7: Ionic Compounds

Ionic compounds are units composed of two distinctly charged parts, the positively charged *cation*, and the negatively charged *anion*. As we will see at Point 12, most ionic compounds are named by putting the cation name before the anion name. Ionic compounds also include the oxyacids (acids of anions containing oxygen), where H^+ is essentially the only cation. These will be described at Point 13.

Point 8: Name the cation

The only difficulty which arises in naming the cation is whether or not to include its charge in the name. When the charge is included, it is listed as a Roman numeral inside parenthesis after the element's name. Many of these cases also have a common name which should be learned as well, since they are still in use in some laboratories. *Note that you must not include the charge where it is not necessary to do so.*

Aside: If you just wish to name the cation by itself, follow the rules for naming the cations in the points below, and add the word "ion" to the end of the name.

Examples: Na^+ is the "sodium ion" (Point 9)
Zn^{2+} is the "zinc ion" (Point 10)
Sn^{4+} is the "tin (IV) ion" or the "stannic ion" (Point 11)

Point 9: Group I, II, and III Cations & Polyatomic Cations

All of these cations have a charge which virtually never varies. Because of this, the charge is understood and is NOT included in the name. These charges are:

All Group I cations of metals have a 1+ charge. (Hydrogen is not a metal!)
All Group II cations have a 2+ charge.
All Group III cations of metals have a 3+ charge. (Boron is not a metal!)

Exception: Thallium, in Group III, can have a charge of 1+ as well as 3+, and should be named following the rules of Point 11. However, you are not likely to encounter examples of either cation in beginning courses.

Polyatomic ions are ions composed of one or more atoms (mostly non-metal atoms, but transition elements are often encountered as well) held together by covalent bonds. These ions are treated as a unit and are associated with a charge that must be learned. In naming compounds it is essential that you be able to recognize these ions on sight, and with practice this will become easy.

There is only one common polyatomic cation, the ammonium ion: NH_4^+.

Other polyatomic cations do exist but they are rarely encountered. They are the uranyl ion, UO_2^{2+}, and the vanadyl ion, VO^{2+}.

Point 10: Cations with only one common charge

Three other elements form cations whose charge virtually never varies. As with Point 9, the charge of the cation is NOT included in the name.

Silver only forms the Ag^+ ion.
Zinc only forms the Zn^{2+} ion.
Cadmium only forms the Cd^{2+} ion.

Most common nickel compounds include the Ni^{2+} ion, but it is common to still include the charge in the name (i.e. nickel(II)), as the Ni^{3+} ion is known to exist. This procedure is not used for silver: the Ag^{2+} ion does exist in some compounds, but is encountered very rarely.

Point 11: Cations with multiple possible charges & cations with common names

All the cations not described in Points 9 and 10 must include the charge in their name. Alternatively, for some cations a common name may be used instead. Most of these cations are derived from transition metals, but some main-group elements such as lead and tin also use these rules. Again, the names of these compounds are formed by adding a Roman numeral in parenthesis to the end of the element's name. So, Sn^{4+} is the tin(IV) ion, and Hg^{2+} is the mercury(II) ion.

When presented with a compound containing one of these cations, the first thing that must be done is to determine the charge on the cation. This is done by considering the total charge of the anion (this can be done since the charges of anions virtually never vary). Consider the following example.

<u>Example:</u> Both of the following contain the oxide ion, O^{2-}.
<u>CuO</u>: There is no charge on this compound, so the total charge of the cation and anion must add up to zero. Since there is only one oxide ion present (charge 2-), and there is only one copper ion to cancel out this charge, it must have a 2+ charge. Therefore, the cation here is copper(II) ion.
<u>Cu_2O:</u> Again the total charge adds up to zero. Now there are two copper ions present to cancel out the 2- charge of oxide.

Each copper cation must have a charge of 1+ (two copper cations, each contributing 1+ gives a total of 2+, canceling out oxide ion's 2-.) The cation is copper(I) ion.

This same logic can be used in reverse if you are given the name of a compound and asked for its formula.

Important Fact to Know: The mercury(I) ion, Hg_2^{2+}, is actually found as a pair of mercury atoms which jointly share the charge between them. It can technically be considered a polyatomic cation. The "2" subscript must never be cancelled out if it occurs in a formula (e.g. mercury(I) chloride is Hg_2Cl_2 rather than HgCl).

Cations with common names: Several of these cations have common names which are used to distinguish which cation has the greater charge of the pair. Unfortunately, to use these common names correctly you must memorize the charge associated with each cation. In addition, some of these names are derived from the original Latin element names. You will notice that the ion with the greater charge of the two ends in "-ic", and the other ends in "-ous." You should know at least the first four sets from this list as you will encounter them most often in the course.

Ion	Common Name	Ion	Common Name
Cu^{2+}	cupric ion	Cu^{+}	cuprous ion
Fe^{3+}	ferric ion	Fe^{2+}	ferrous ion
Pb^{4+}	plumbic ion	Pb^{2+}	plumbous ion
Sn^{4+}	stannic ion	Sn^{2+}	stannous ion
Hg^{2+}	mercuric ion	Hg_2^{2+}	mercurous ion
Cr^{3+}	chromic ion	Cr^{2+}	chromous ion
Co^{3+}	cobaltic ion	Co^{2+}	cobaltous ion
Mn^{3+}	manganic ion	Mn^{2+}	manganous ion

Point 12: Name the anion and combine the two names, cation first

There is good news and bad news in naming the anions. The good news is that the charge does not change from anion to anion (chloride ion is always Cl^-, never Cl^{2-}, Cl^{3-}, etc.) The bad news is that there are many polyatomic anions whose names must be memorized, and many of these anions can be slightly modified, such as by adding an oxygen atom, changing their name. To name the anion we will consider another flowchart prepared especially for anions as well as the acids derived from them. Start at the top of the anion flowchart and follow the path to each point necessary like you did with the first chart.

Once you find the name of your anion, write down the name of the cation (which you found in the previous step), then follow it with the name of your ion. Note that the word "ion" is itself not included in the name of a compound (e.g. NaCl is "sodium chloride", not "sodium ion chloride ion"!)

Point A: Monatomic anions

The charge on monatomic ions can be determined by the group number of the ion:

Group VII anions have a 1- charge (F^-,. Cl^-, Br^-, I^-), as does the hydride ion(H^-)
Group VI anions have a 2- charge (O^{2-}, S^{2-}, Se^{2-}, Te^{2-})
Group V anions have a 3- charge (N^{3-}, P^{3-}, As^{3-})
The group IV anion carbide has a 4- charge (C^{4-})

Naming these ions simply requires you to change the ending of the element's name to "-ide." Examples include oxide (O^{2-}), sulfide(S^{2-}), nitride (N^{3-}), and phosphide (P^{3-}).

Point B: Polyatomic anions

Common anions to know: You should memorize the polyatomic anions in the following table. Pay special attention to those anions which contain a non-metal preceding oxygen in the formula; these are the oxyanions, and special rules will apply to them. Note that all the oxyanions on the list end in "-ate."

	1- anions		
OH^-	hydroxide	NO_3^-	nitrate
CN^-	cyanide	ClO_3^-	chlorate
OCN^-	cyanate	BrO_3^-	bromate
SCN^-	thiocyanate	IO_3^-	iodate
MnO_4^-	permanganate	$C_2H_3O_2^-$	acetate
	2- anions		
CO_3^{2-}	carbonate	SO_4^{2-}	sulfate
CrO_4^{2-}	chromate	$Cr_2O_7^{2-}$	dichromate
$C_2O_4^{2-}$	oxalate	SiO_3^{2-}	silicate
$S_2O_3^{2-}$	thiosulfate	O_2^{2-}	peroxide
	3- anions		
PO_4^{3-}	phosphate	BO_3^{3-}	borate

Many other anions can be derived from the oxyanions, depending on the number of oxygen atoms in the ion. For example, the chlorite ion, ClO_2^- resembles the chlorate ion; however chlorite has one less oxygen in its formula than does chlorate. **It is vital that you notice similarities of this type!**

Point C: Naming oxyanions

If your anion is an oxyanion, the first thing you must ask yourself is if it is one of the "-ate" oxyanions. By this I mean the oxyanions that end in "-ate" on the list of the polyatomic anions above. If it is, you can proceed to the next step. If it has an additional or fewer oxygen atoms, make the changes below to the name:

If it has one more oxygen atom than the one on the list, add the prefix “per-.”
Example: ClO_3^- is chlorate, so ClO_4^- is perchlorate.
If it has one less oxygen atom than the one on the list, change the ending from “-ate” to “-ite.”
Example: ClO_3^- is chlorate, so ClO_2^- is chlorite.
If it has *two* less oxygen atoms than the one on the list, change the ending from “-ate” to “-ite” AND add the prefix “hypo-.”
Example: ClO_3^- is chlorate, so ClO^- is hypochlorite.

Point D: Hydrogen containing anions

Some anions have a proton (H^+) added to their formula. It will always come at the beginning of the anion. If one proton is added to the formula, change the name of the anion by putting the word “hydrogen” before it. Likewise, if two protons are added to the formula, put the word “dihydrogen” before the anion’s name.

Example: PO_4^{3-} is “phosphate”, so HPO_4^{2-} is the hydrogen phosphate ion, and $H_2PO_4^-$ is the dihydrogen phosphate ion.

You must notice that each time a proton is added to the formula, a positive charge is added to the ion’s charge, making it more positive.

Sometimes, when one hydrogen atom is added to the formula, the prefix “bi-” is added rather than adding the word “hydrogen.” So, HCO_3^- can be called either the bicarbonate ion or the hydrogen carbonate ion.

Notice that the total number of hydrogens added must never completely cancel out the charge of the anion! If it does, then the compound is an acid (see Point 13). If you followed the flowchart correctly, you should never have reached Point 12 on the flowchart

Point 13: Oxyacids

Oxyacids seem to give beginning chemistry students more trouble than any other type of compound. The naming rules for these are straightforward, yet they still manage to confuse many students. *Before you name this type of compound, it is essential that you thoroughly understand the naming of oxyanions as it was described in Point C.*

First of all, we need to make sure that you’re in the right spot. Oxyacids contain exactly as many protons (H^+) as are necessary to totally balance out the negative charge of the anion. No other cations should be present in the compound’s formula. So H_3PO_4 (3 protons balance out the 3- charge of phosphate ion) is an oxyacid, but KH_2PO_4 is not (it contains the potassium ion).

Procedure: First look at the anion of the acid.

If the anion’s name ends in “-ate”, then change the “-ate” to “-ic acid”

Example: $HClO_3$ The anion is chlorate (ClO_3^-), so the name of the acid is chloric acid.

Example: $HClO_4$ The anion is perchlorate (ClO_4^-), so the name of the acid is perchloric acid.

If the anion's name ends in "-ite", then change the "-ite" to "-ous acid"

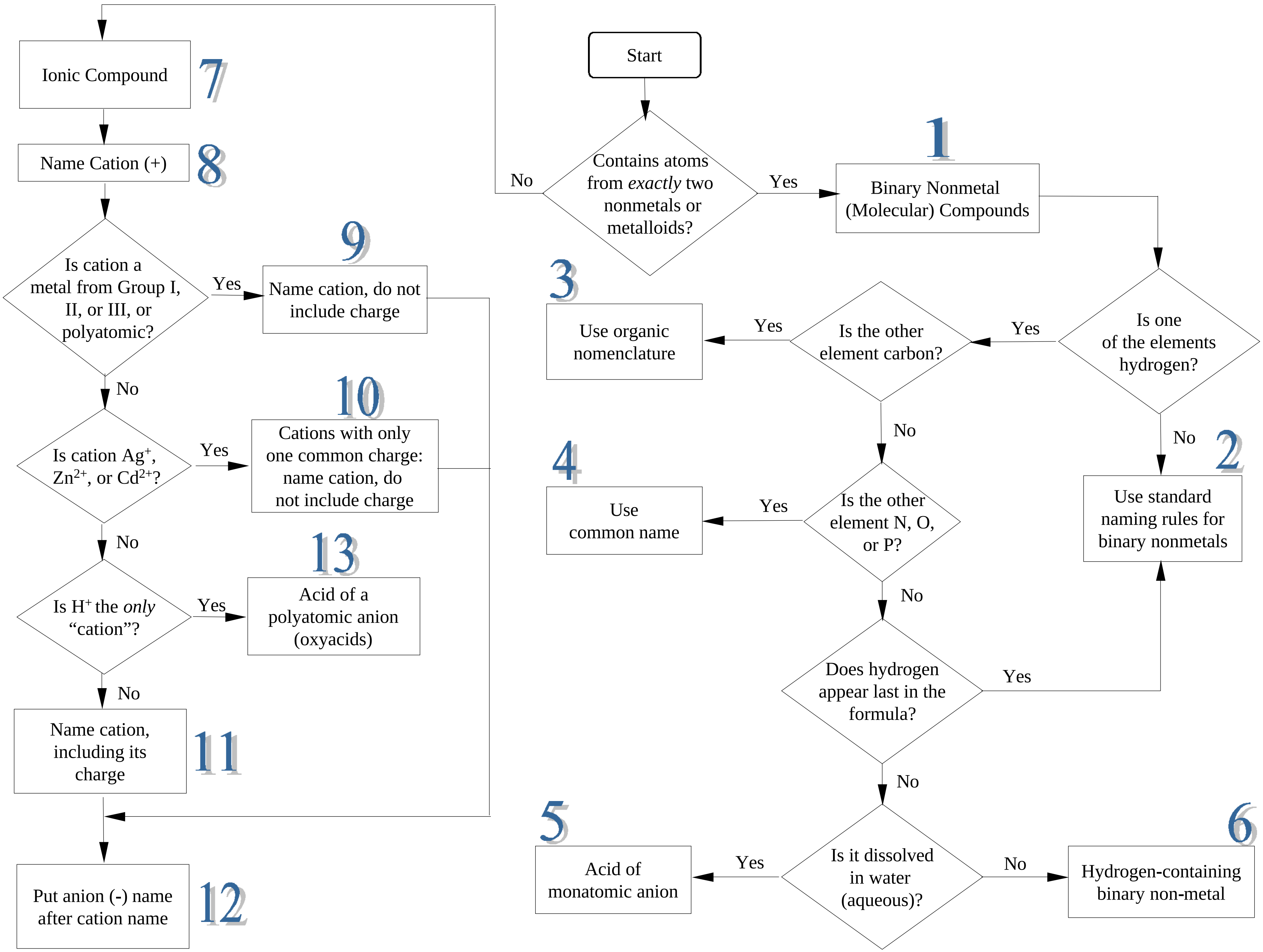
Example: $HClO_2$ The anion is chlorite (ClO_2^-), so the name of the acid is chlorous acid.

Example: HClO The anion is hypochlorite (ClO^-), so the name of the acid is hypochlorous acid.

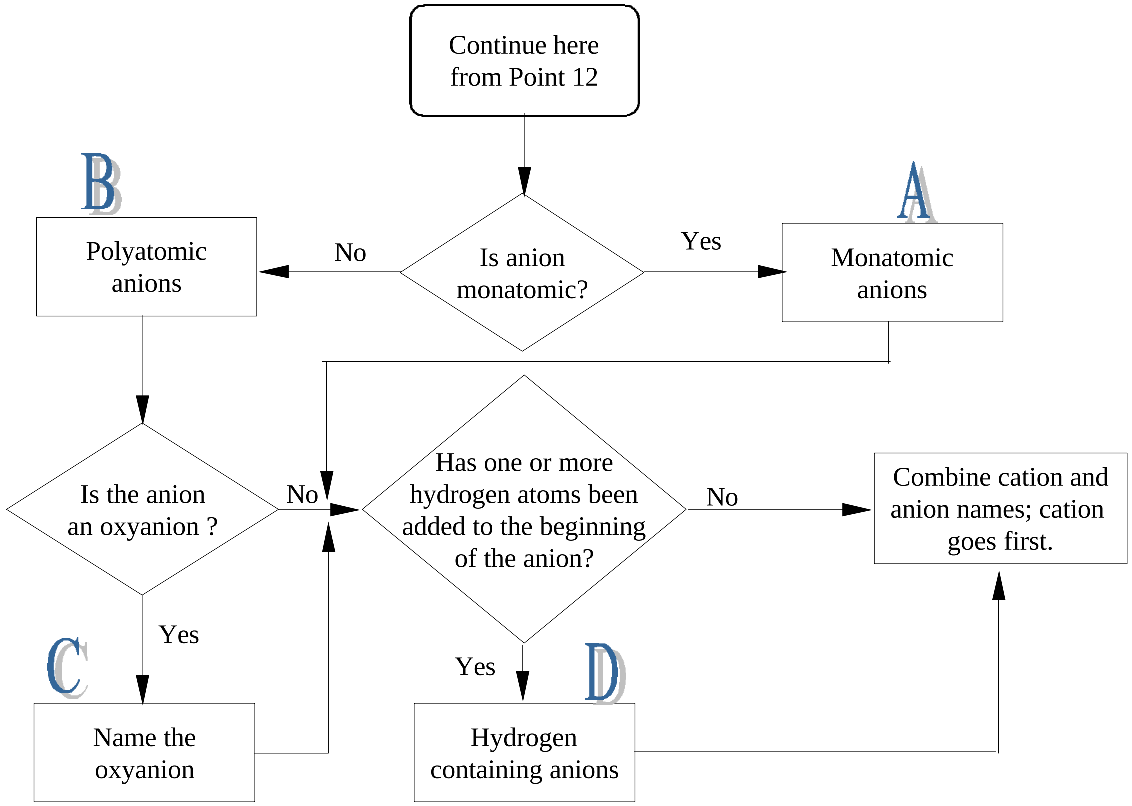
Exceptions: For acids based on the sulfate ion (SO_4^{2-}), you must use the root "sulfur" rather than just "sulf." So, H_2SO_4 is sulfuric acid (not sulfic acid), H_2SO_3 is sulfurous acid, etc.

For acids based on the phosphate ion (PO_4^{3-}), you must use the root "phosphor" rather than just "phosph". So, H_3PO_4 is phosphoric acid (not phosphic acid), H_3PO_3 is phosphorous acid, etc.

Incidentally, you might have ended up at Point 13 inadvertently if you were trying to name the compound HCN. The name for this compound is hydrocyanic acid.



Start
Contains atoms from *exactly* two nonmetals or metalloids?
Yes
No
1
Binary Nonmetal (Molecular) Compounds
Is one of the elements hydrogen?
Yes
No
2
Use standard naming rules for binary nonmetals
Is the other element carbon?
Yes
No
3
Use organic nomenclature
Is the other element N, O, or P?
Yes
No
4
Use common name
Does hydrogen appear last in the formula?
Yes
No
Is it dissolved in water (aqueous)?
Yes
No
5
Acid of monatomic anion
6
Hydrogen-containing binary non-metal
7
Ionic Compound
8
Name Cation (+)
Is cation a metal from Group I, II, or III, or polyatomic?
Yes
No
9
Name cation, do not include charge
Is cation Ag^+, Zn^{2+}, or Cd^{2+}?
Yes
No
10
Cations with only one common charge: name cation, do not include charge
Is H^+ the *only* "cation"?
Yes
No
13
Acid of a polyatomic anion (oxyacids)
11
Name cation, including its charge
12
Put anion (-) name after cation name


Continue here from Point 12
Is anion monatomic?
No
Yes
B
Polyatomic anions
A
Monatomic anions
Is the anion an oxyanion ?
No
Has one or more hydrogen atoms been added to the beginning of the anion?
No
Combine cation and anion names; cation goes first.
Yes
C
Name the oxyanion
Yes
D
Hydrogen containing anions