Chapter 4 CHEMICAL UNITS AND THEIR IDENTITIES, Part 3

As we've been going through these parts, I've mentioned quite a few compounds but only a few names. Now we need to get into names in more detail.

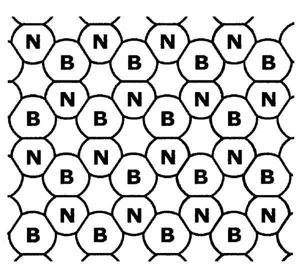
4.1 What's in a name?

Compound names are a critically important part of chemistry and its language. A name reflects identity. Names are typically based on formulas and vice versa. Working with these is much like language translations, such as English-into-Latin and Latin-into-English. In chemistry, it's formula-into-name and name-into-formula. The translations involve a lot of memorization. If you're going to talk the talk, you need to know some words. Besides, chemical names are part of your world, whether you like it or not and whether you learn it or not. They're on the labels of the foods you eat and the things you smear on your body. Read the ingredients. Do you know what they are? Do you care? There are more chemical names on the labels in a grocery store than there are on the labels in many chemistry laboratories. Chemical names are everywhere. Go look at a label. Try a label on a box of cereal. If you want an extreme example, look at a bottle of multi-vitamins.

There are various naming systems in chemistry designed for various types of compounds. Our emphasis here will be ionic compounds and certain covalent compounds. The naming of these types of compounds has become fairly consistent over the years although there are variations in the way the systems are taught. The steps which I cover here may be different from the way your instructor does it, but the answers should come out the same. This is just an example of "multiple methods" which I mentioned in Chapter 1.

Let's go back to formulas for a moment. A formula shows the elements involved and the number of atoms of these. This is two-thirds of identity for a compound. The other third is the arrangement of the atoms in the chemical unit. Often, we can determine the arrangement from the formula, but, unfortunately, that's not true of everything. For example, I mentioned isomers in the last Chapter: they have the same chemical formula and the same number of the same atoms, but the atoms are in different arrangements. Thus, a formula by itself may not be enough for identity, and other information must also be given. We won't be worrying about that here, however, since we will be sticking to the easier cases for now.

For molecules and for polyatomic ions, the formula gives the exact numbers of atoms in each chemical unit. H_2O means two H and one O in every single water molecule. SO_3^{2-} means one S and three O in every single sulfite ion. This relationship does not hold true for networks. In a network, everything's bonded somehow in one, two or three dimensions. The whole thing is the chemical unit. Thus, the formula of a network compound is handled differently. For a covalent network compound, the formula is the smallest, whole-number ratio of the different atoms involved. I mentioned last Chapter that quartz is a network covalent compound with the formula SiO_2. There are no SiO_2 molecules in quartz. There are one zillion Si atoms and two zillion O atoms bonded together in three dimensions. That's what the formula means: twice as many O's as Si's. Since the bonds extend in three dimensions, quartz is a 3D network.



Here's another example of a covalent network compound, but this one is 2D: boron nitride, BN. The formula means that there are equal numbers of boron atoms and of nitrogen atoms. There are no individual BN molecules in the solid; there are a zillion B's and a zillion N's bonded to each other. In this compound, all the bonds lie in a plane in two dimensions. This makes BN a two-dimensional network. One such layer is shown at left. The actual solid will have a huge number of these layers stacked on top of each other but there are no chemical bonds between the different layers.

All ionic compounds are network compounds. For an ionic compound, the formula is the smallest, whole-number ratio of cations and anions. Examples which I mentioned last Chapter include NaCl and $NaNO_3$. Ionic formulas are ratios. In NaCl and $NaNO_3$, the cation:anion ratio is 1:1. Many ionic compounds have other ratios. $MgBr_2$ means one Mg^{2+} cation for every two Br^- anions. K_3PO_4 means three K^+ cations for every one PO_4^{3-} anion. (PO_4^{3-} is another polyatomic anion.)

I want to repeat three sentences from the above paragraphs. They're critically important to understanding the meaning of a formula.

FOR MOLECULES AND FOR POLYATOMIC IONS, THE FORMULA GIVES THE EXACT NUMBERS OF ATOMS IN EACH CHEMICAL UNIT.

FOR A COVALENT NETWORK COMPOUND, THE FORMULA IS THE SMALLEST, WHOLE-NUMBER RATIO OF THE DIFFERENT ATOMS INVOLVED.

FOR AN IONIC NETWORK COMPOUND, THE FORMULA IS THE SMALLEST, WHOLE-NUMBER RATIO OF CATIONS AND ANIONS.

I need to warn you about something. At first glance, the covalent network and the ionic network sentences appear to be similar. Both are smallest, whole-number ratios, but there's a subtle difference for ionics. The ionic formula is an <u>ion</u> ratio, not an <u>atom</u> ratio. Does this matter? Yes, it can. Let me give you an example using $C_2O_4^{2-}$, which is another polyatomic anion. If we combine the anion $C_2O_4^{2-}$ with K^+ cations, we get the ionic compound $K_2C_2O_4$. That's the correct formula, since it properly says that there are two K^+ cations for every one $C_2O_4^{2-}$ anion. That's the smallest, whole-number <u>ion</u> ratio. If we tried to write the smallest, whole-number <u>atom</u> ratio, we would get "KCO_2", but that implies that the anion is CO_2^- and that is wrong. (CO_2^- does not even exist as a common ion.) Thus, there can be a difference between a smallest atom ratio and a smallest ion ratio, and you need to remember the distinction.

I want to define a new term at this time. It's "formula unit". A formula unit is the number and type of atoms given by the formula. This term is generic and it can apply to anything, regardless of the real chemical unit. Sometimes the formula unit will be the same as the real chemical unit. For a molecular compound such as water, H_2O, the formula unit and the chemical unit are the same, so that's no big deal. For all network compounds, however, the formula unit is not the same as the chemical unit. Let's consider quartz (SiO_2) again. The formula unit is just one Si and two O's, but that's not the real chemical unit. The chemical unit is the whole network of one zillion Si atoms and two zillion O atoms. The term "formula unit" is useful because we can use it without even knowing whether the compound is molecular or network. Just keep in mind that the formula unit does not necessarily indicate the true chemical unit.

OK, let's get into actual names.

4.2 We start with ionics.

The name of an ionic compound is just the name of the cation followed by the name of the anion. In order to do that, we must first consider how to name cations and anions by themselves. Then we'll put them together for the ionic compound as a whole.

For purposes of naming the separate ions, we return to the four categories of monatomic ions and their charges as we had done in Chapter 3. You flagged that part: go back and look those over right now. You still need to know those monatomic ion charges. In this Chapter, we will add a fifth category for polyatomic ions. As we go, I'll show examples of names and formulas but I'll leave some blanks. You have to fill in the blanks.

• CATEGORY 1. CONSTANT CHARGE CATIONS

The name of the ion is simply the name of the element. No big deal here.

‣ Na^+
Na stands for sodium. It is in Group 1 and its charge is 1+. The name is sodium ion.

‣ barium ion
Barium's symbol is Ba. It's in Group 2, so the charge is 2+. The ion's formula is Ba^{2+}.

‣ Ga^{3+}
Ga stands for gallium. It is located in Group 13 so the ion charge will be 3+. The name is gallium ion.

Your turn.

‣ What is the formula for lithium ion? ___________

‣ What is the name for Ca^{2+}? ______________________

‣ What is the formula for aluminum ion? ___________

• CATEGORY 2. VARIABLE CHARGE CATIONS

The name of the ion is the name of the element followed by the charge. The charge is shown in Roman numerals in parentheses immediately after the element with no spaces in between.

‣ Fe^{2+} and Fe^{3+}
Fe is the symbol for iron. Fe^{2+} is named iron(II) ion. Fe^{3+} is named iron(III) ion.

Notice that the parentheses butt right up against the element name with no space in between. It's written iron(II), not iron (II) with an extra space. Let me also note that when we speak the names, then the charge number is also spoken. Iron(II) ion is pronounced as "iron-two" ion. The name of Fe^{3+} is pronounced "iron-three" ion.

‣ lead(II) ion and lead(IV) ion
Lead's symbol is Pb. The formula of lead(II) ion is Pb^{2+}. The formula of lead(IV) ion is Pb^{4+}.

‣ Cu^{+} and Cu^{2+}
Cu is the symbol for copper.
Cu^{+} is named copper(I) ion. What's the name of Cu^{2+}? ____________________

‣ gold(I) ion and gold(III) ion
Gold's symbol is Au.
The formula of gold(I) ion is Au^{+}. What is the formula for gold(III) ion? __________

Keep going.

‣ What is the formula of nickel(II) ion? __________

‣ What is the formula of nickel(III) ion? __________

‣ What is the name of Sn^{2+}? ____________________

‣ What is the name of Sn^{4+}? ____________________

• CATEGORY 3. CONSTANT CHARGE ANIONS

These take a suffix: the name of the ion is the root name of the element, then *-ide* as an ending.

‣ I^{-}
I stands for iodine. The ion name is formed from the root *iod-* and suffix *-ide*, giving the name iodide ion.

‣ oxide ion
Ox- is root for oxygen, O. It's in Group 16, so the charge is 16 – 18 = 2–. The ion's formula is O^{2-}.

‣ N^{3-}
N stands for nitrogen. The name is nitride ion which is formed from the root *nitr-* and the suffix *-ide*.

Your turn.

‣ What is the formula of bromide ion? __________

‣ What is the name of As^{3-}? ____________________

‣ What is the formula of sulfide ion? __________

• CATEGORY 4. HYDROGEN

The H^{+} cation takes a normal cation name, hydrogen ion. The H^{-} ion takes a normal anion name, hydride ion. That's all there is for this Category. Again, there are no compounds with the H^{+} ion, but the cation does exist by itself in outer space and it can be generated instrumentally on Earth for very short periods of time.

• CATEGORY 5. POLYATOMIC IONS

As I had mentioned previously, the names and formulas of polyatomic ions are pretty much a memorization job. You'll need to know a list. I'll give a list of ions which are fairly common in many first-year courses, some of which I'll call upon in this book. Your instructor may use this list or parts of it, and s/he may add more. I'll leave some space below so you can write in any more from your instructor's need-to-know list.

A. POLYATOMIC CATIONS

By far, the most common polyatomic cation is ammonium ion. Besides that, I'll add mercury(I) ion to the list. Mercury(I) happens to be diatomic, although it is often mistaken for a monatomic. (In comparison, mercury(II) ion is monatomic, like most transition metal ions.)

ammonium ion, NH_4^+

mercury(I) ion, Hg_2^{2+}

Your instructor may list other polyatomic cations. Add them into the space above.

B. POLYATOMIC ANIONS

Anions are a different story. There are many different polyatomic anions and many are commonly encountered in a first-year course. Here are some, grouped according to their charges.

Polyatomic Anions of 1– Charge

acetate ion, $C_2H_3O_2^-$ or $CH_3CO_2^-$
chlorite ion, ClO_2^-
hydroxide ion, OH^-
nitrate ion, NO_3^-
perchlorate ion, ClO_4^-
chlorate ion, ClO_3^-
cyanide ion, CN^-
hypochlorite ion, ClO^-
nitrite ion, NO_2^-
permanganate ion, MnO_4^-

Add others from your instructor's list here, if any:

Polyatomic Anions of 2– Charge

carbonate ion, CO_3^{2-}
oxalate ion, $C_2O_4^{2-}$
sulfite ion, SO_3^{2-}
chromate ion, CrO_4^{2-}
sulfate ion, SO_4^{2-}
thiosulfate ion, $S_2O_3^{2-}$

Add others from your instructor's list here, if any:

Polyatomic Anions of 3– Charge

arsenate ion, AsO_4^{3-}
phosphate ion, PO_4^{3-}

Add others from your instructor's list here, if any:

Most of the anions above are oxyanions of various elements. An oxyanion is a polyatomic anion composed of one or more oxygen atoms bonded to an atom of one other element other than H. For example, we say ClO_3^- is an oxyanion of chlorine; we say NO_3^- is an oxyanion of nitrogen; etc. Many elements form oxyanions, and, in fact, many elements form more than one oxyanion. The different oxyanions for one element vary in the number of oxygens which are bonded in the chemical unit. There is a pattern to naming these; I want to show you the pattern so that it can help with naming.

For each element which forms oxyanions, one of these gets a name ending in the suffix *-ate*; this suffix is attached to the element's name or root name. For example, there's chlor<u>ate</u> (ClO_3^-), nitr<u>ate</u> (NO_3^-), carbon<u>ate</u> (CO_3^{2-}), sulf<u>ate</u> (SO_4^{2-}), phosph<u>ate</u> (PO_4^{3-}), etc. When one element forms two or more different oxyanions, then their names are related to this *-ate* form. In the polyatomic anion list above, there are several oxyanions for the elements N, S and Cl; their formulas vary by the number of oxygen atoms. Let's look at how the oxyanion names for these are related according to the number of oxygens present.

Start with the element's *-ate* form. Know (memorize) this form for each element which is under consideration.

nitrate, NO_3^-

sulfate, SO_4^{2-}

chlorate, ClO_3^-

It would have been nice if all *-ate* forms for all elements had the same number of O's and the same charges, but that's not what happened. You just have to remember each case.

If the element has another oxyanion with one less oxygen atom than the *-ate* form, then change the suffix *-ate* to *-ite*.

nitrate, NO_3^-	nitrite, NO_2^-
sulfate, SO_4^{2-}	sulfite, SO_3^{2-}
chlorate, ClO_3^-	chlorite, ClO_2^-

If the element has another oxyanion with even one less oxygen than the *-ite* form, then the prefix *hypo-* is added. These anions are not as common; I will continue here with Cl only.

chlorate, ClO_3^- chlorite, ClO_2^- hypochlorite, ClO^-

Still continuing only with Cl, now we'll back up to the beginning at chlorate, ClO_3^-, and head the other direction. For an oxyanion with one more oxygen than the *-ate* form, then the prefix *per-* is added.

perchlorate, ClO_4^- chlorate, ClO_3^- chlorite, ClO_2^- hypochlorite, ClO^-

This concludes the most common pattern of naming different oxyanions for a particular element.

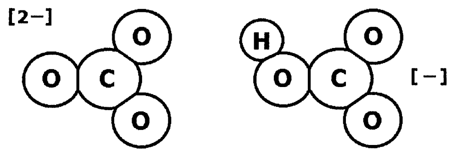
If you understand the oxyanion relationships, it will help you to know the names and formulas of the different oxyanions for a given element. Although not in the list above, there are many more oxyanions of other elements. For example, selenium forms selenate and selenite anions; bromine has perbromate, bromate, bromite and hypobromite ions. Thus, if you know the oxyanion naming pattern, then this can help for more element cases. This pattern is very historical. The full system has some quirks and there are more parts to it, but this is all we need to worry about right now.

To the extent of our coverage, here are three things to keep in mind for the different oxyanions of any one element.

First, the different oxyanions for an element vary only in the number of oxygens which are bonded in the chemical unit.
Second, the different oxyanions of the same element have the same charge.
Third, all different oxyanions are different chemical units. All have different properties. I mentioned in the last Chapter that sulfite (SO_3^{2-}) can kill while sulfate (SO_4^{2-}) is fairly harmless. This is not a small difference, it is a big difference. Different oxyanions are different chemical units. They are different identities. They do different things.

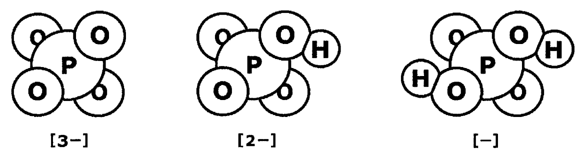
There is another group of polyatomic ions which I need to describe. These are not listed above, but they are related to many monatomic and polyatomic anions in general. This grouping is related by one or more hydrogens which are covalently bonded within the chemical unit; because of this, these are called "hydrogen anions". For every hydrogen in the unit, there is a reduction of the anion charge by one. There's a very common example here and that's the anion in baking soda, HCO_3^-. It is the hydrogen anion of CO_3^{2-} but it is a polyatomic anion by itself and it has its own identity. Hydrogen anions are named by adding the word "hydrogen" (or "dihydrogen" if two) in front of the related anion name. CO_3^{2-} is carbonate; HCO_3^- is hydrogen carbonate. There's also a traditional naming method which is still very common and which uses a prefix *bi-* instead of the separate word "hydrogen". In this manner, HCO_3^- is also called bicarbonate. That's the word you'll see on your box of baking soda. Baking soda is sodium bicarbonate, $NaHCO_3$, which we can also call sodium hydrogen carbonate. Why the prefix "*bi-*"? This prefix is usually associated with two of something and that's how it originally started, but the explanation is too ugly to worry about right now. Just remember how it's used with hydrogen anions.

The hydrogens are bonded by covalent bonding within the polyatomic anion. Hydrogen anions are their own chemical unit and have their own identity. Look at CO_3^{2-} and HCO_3^-, at left. Since they are different chemical units, they have different properties. Bicarbonate is relatively mild to living tissue but carbonate is much harsher. Sodium carbonate (Na_2CO_3) is used in detergent products which are not intended to be used in direct human contact, such as some laundry and dishwasher detergents. Read the labels. It's been known as washing soda for many years, just like sodium bicarbonate has been known as baking soda.



There are a lot of hydrogen anions. Another example is hydrogen sulfate ion, HSO_4^-, also called bisulfate ion; this is the hydrogen anion of sulfate ion, SO_4^{2-}. I earlier said the sulfate ion is fairly harmless. On the other hand, hydrogen sulfate ion is fairly acidic. They used to use sodium hydrogen sulfate as a common toilet bowl cleaner; that use has been phased out although it is still used as a food additive.

Let's consider phosphate ion, PO_4^{3-}, which has two related hydrogen anions, HPO_4^{2-} and $H_2PO_4^-$. HPO_4^{2-} is called hydrogen phosphate ion and $H_2PO_4^-$ is called dihydrogen phosphate ion. Notice the *di*- prefix for two hydrogens. Again, these are all different chemical units with different properties.



Getting the hang of this? Let's find out. Fill in the blanks.

‣ What is the formula of bisulfite ion? ________________

‣ What other name can it go by? ____________________________________

‣ What is the formula of dihydrogen arsenate? ________________

‣ What are two names for HS^-? ____

In summary, remember the following three points for hydrogen anions.

First, the hydrogen anions are related to other anions by the presence of H's in the chemical unit.
Second, the charge of the hydrogen anions is one less negative for every H.
Third, the different hydrogen anions are different chemical units and have different properties.

Here's a common student error. Some students think a hydrogen anion is composed of two ions, H^+ and an anion. For example, they think bicarbonate is H^+ and CO_3^{2-} together in the compound. This is wrong. The H is covalently bonded within the chemical unit of the hydrogen anion. There is no separate H^+ ion.

Here's a different twist: can you have a hydrogen anion for chlorate, ClO_3^-? The answer is no. If you add the H and reduce the charge, you get $HClO_3$ which is neutral. This is a neutral compound and it does exist, but it's not a hydrogen anion. This is a general result: you cannot have a hydrogen anion for the 1− anions. All of those would be neutral compounds.

4.3 We're ready to name an ionic compound.

We just spent a lot of time naming the separate cations and the separate anions. Now let's go to the names of ionic compounds. We'll start with a formula and write the name of an ionic compound. After that, we'll start with a name and write the formula. There are several points to note right away.

First, the name of an ionic compound is simply the name of the cation followed by the name of the anion.
Second, the formula of the ionic compound shows the cation first and then the anion.
Third, the formula of an ionic compound must represent a neutral compound in the smallest, whole number ratio of ions. Remember that Nature demands neutrality for ionic compounds. The total cation charges must equal the total anion charges.

Let's start with several examples and I'll describe them in full detail from the beginning. Work through these. Be certain you understand these descriptions. If not, go back and read the relevant parts above.

‣ $BaCl_2$

This ionic compound is composed of cations and anions in a 1:2 ratio. Barium is in Group 2 so it's a constant charge cation with a 2+ charge. Its name is barium ion. Chlorine is in Group 17 so its anion's charge is 17 − 18 = 1−; its name is chloride ion. The name of the ionic compound is therefore barium chloride. Like all ionic compounds, this is a network compound and the 1:2 ratio simply means there are twice as many anions as cations. The ratio must be 1:2 in order for the charges to cancel: the charge of each Ba^{2+} cancels two Cl^- charges.

Here's another pointer. In the formula of the ionic compound as a whole, no charges are shown. That's because the ionic compound as a whole is neutral. You must still remember that the formula of an ion by itself must show its charge.

‣ KNO_3

This ionic compound is composed of cations and anions in a 1:1 ratio. Potassium is in Group 1; it's a constant charge cation with a 1+ charge. Its name is potassium ion. The anion is the polyatomic anion, NO_3^-, whose name is nitrate ion. You would need to recognize that formula from your knowledge (memorization) of the polyatomics. The name of the ionic compound is potassium nitrate. Again, this is an ionic network compound; the 1:1 ratio means that there are equal numbers of cations and anions present. The ratio must be 1:1 in order for the charges to cancel: each K^+ charge cancels each NO_3^- charge.

‣ $Ca(ClO)_2$

This ionic compound is composed of cations and anions in a 1:2 ratio. Calcium is in Group 2 so it's a constant charge cation with a 2+ charge. Its name is calcium ion. The anion is in parentheses and it's the polyatomic anion, ClO^-, whose name is hypochlorite ion. This example introduces the use of parentheses; parentheses are used to enclose a polyatomic ion if more than one is indicated in the formula. Overall, the name of the ionic compound is calcium hypochlorite. The 1:2 ratio means that there are twice as many anions as cations present. The ratio must be 1:2 in order for the charges to cancel: the charge of each Ca^{2+} cancels two ClO^- charges.

Let me say a bit more about the parentheses. They're needed to keep the polyatomic's identity clear. For example, you cannot write the formula as $CaClO_2$: that says the anion is ClO_2^{2-}, which is wrong. You also can't write the formula as $CaCl_2O_2$: that says the polyatomic ion is $Cl_2O_2^{2-}$, which is wrong. You need to use parentheses here. When dealing with parentheses, remember this: the <u>identity</u> of the polyatomic ion is <u>inside</u> the parentheses while the <u>ion ratio</u> is subscripted <u>outside</u> the parentheses. This is important. And, by the way, don't overdo parentheses either. Don't use them on monatomics. For example, don't write $(Ca)(ClO)_2$.

Ever use calcium hypochlorite? The pure compound is nasty stuff but it's frequently mixed with other compounds for easier handling. It's one of the most common chlorine compounds used by people in their home swimming pools to disinfect, control algae, etc. Higher doses are used in commercial products for "shocking" a pool. Read the label. It's on there. That's right, you may swim in a solution of the stuff.

‣ $Cr_2(SO_4)_3$

This ionic compound is composed of cations and anions in a 2:3 ratio. Chromium is a member of the variable charge cation category. That means that we have to figure out its charge here and we need to add a Roman numeral to the name. The anion is inside the parentheses and it's the polyatomic anion, SO_4^{2-}, whose name is sulfate. We can figure out the cation charge from the total anion charges and the requirement of neutrality. Here's how that's done:

You have three 2− anions for a TOTAL of 6− anion charges in the formula.
The total cation charges must cancel this, which means the cations must TOTAL 6+.
The formula tells you there are two cations, so <u>each</u> cation must be 3+.

We therefore conclude that the cation is Cr^{3+}, the chromium(III) ion. The name of the ionic compound is chromium(III) sulfate. I mentioned the pronunciation of variable charge cations earlier; here's a compound with one. For the compound name, you still verbalize the charge number: the name is pronounced "chromium-three sulfate".

These variable charge cases take an extra step for converting from formula into name. Fortunately, it's payback time when translating in the reverse direction, name into formula. We'll see that later.

Alright, your turn. We'll work through some examples. Fill in the blanks as you go. I won't give all of the answers, so it's up to you to get them right. Questions? Go back and read the necessary sections. Ask a friend. Or ask your instructor.

▸ $Mg(OH)_2$

Is the cation of constant charge or variable charge? ____________________

What's the cation's name? ____________________

What's the anion's name? ____________________

What's the compound's name? ____

The very first question was whether the cation is constant charge or variable charge. Constant charge cations, such as in this example, are straightforward. Variable charge cations (later example) require that you figure out the cation charge.

Ever drink a paste of magnesium hydroxide? It's the "blue MOM". Milk Of Magnesia. In the unmistakable blue bottle. Magnesium hydroxide. It's on the label. Read it.

▸ NH_4Br

What's the cation's name? ____________________ (Clue: polyatomic!)

What's the anion's name? ____________________

What's the compound's name? ____

Here's a pointer for you. Ammonium can confuse students at first because they're so used to seeing metal elements as cations. So I'll tell you right now to commit ammonium to memory to the point of automatic recognition. If any formula starts NH_4..., then you need to automatically recognize that as an ionic compound with ammonium cation.

▸ LiH_2AsO_4

Is the cation of constant charge or variable charge? ____________________

What's the cation's name? ____________________

What's the anion's name? ____________________

What's the compound's name? ____

Did you catch the hydrogen anion in this example? They can throw some people off, so be careful. Besides, you did dihydrogen arsenate in one of the examples two pages ago.

▸ $PbCrO_4$

Is the cation of constant charge or variable charge? ____________________

What's the cation's name? ____________________

What's the anion's name? ____________________

What's the compound's name? ____

This one has a variable charge cation, so you could not do the cation name until you took into account the charges. The anion is 2– and the formula says that the ion ratio is 1:1. That tells you that the cation charge is 2+.

By the way, $PbCrO_4$ is a nice looking yellow or yellow-orange powder. It's used as a pigment in oil or water colors. Its pigment name is "chrome yellow". It used to be fairly common but its use has decreased since it's fairly toxic. Most lead compounds are toxic and so also are chromate compounds. So this one's a double whammy.

OK, now we switch translation directions and go from name into formula. The biggest problem in this direction is getting the right ratio for cations and anions. Again, Nature demands neutrality for typical Earth conditions. The ratio must also be in smallest, whole-numbers. I'll give some examples in detail and then we'll work through several.

- sodium nitride
  Sodium is in Group 1 so it forms a cation of 1+ charge with the formula Na^{+}. Nitride is the anion for nitrogen (Group 15) and it has a charge of 15 – 18 = 3–; the formula is N^{3-}. With a cation charge of 1+ and an anion charge of 3–, neutrality requires a 3:1 ratio. The formula is Na_3N.

- zinc acetate
  Zinc is a constant charge cation. The charge is 2+ and the formula is Zn^{2+}. Acetate is a polyatomic anion with charge 1–; its formula is $C_2H_3O_2^-$ or $CH_3CO_2^-$. (Both formulas for acetate say the same thing, so you can use either unless your instructor requires a specific one.) For a cation of 2+ charge and an anion of 1– charge, neutrality requires a 1:2 ratio. The formula is $Zn(C_2H_3O_2)_2$ or $Zn(CH_3CO_2)_2$.

Notice that I had to put parentheses around the polyatomic anion. Notice that the anion's identity is completely inside the parentheses. Notice that the ion ratio is provided by the subscript outside the parentheses.

- tin(IV) sulfide
  OK, the cation charge is a dead giveaway, thanks to the Roman numeral. (Here's the payback I mentioned earlier.) The charge here is 4+ so the ion is Sn^{4+}. Sulfide is the anion for sulfur (Group 16); the anion has a charge of 16 – 18 = 2–, with the formula S^{2-}. For a cation of 4+ charge and an anion 2– charge, neutrality requires a 1:2 ratio. The formula is SnS_2.

- nickel(II) phosphate
  Roman numerals again. Cation charge is 2+ and formula is Ni^{2+}. Phosphate is a polyatomic anion with charge 3– and formula PO_4^{3-}. While it may not be immediately obvious, neutrality requires a 3:2 ratio. The formula is $Ni_3(PO_4)_2$.

While it is fairly easy to recognize 1:1, 1:2, 2:1 and even 1:3 or 3:1 ion ratios, the 2:3 and 3:2 cases are more difficult. Be aware of this. I'll show you a clue for dealing with these in a moment.

Alright, your turn again. We'll work through some examples.

- silver bisulfate

  What's the cation's charge? ___________

  What's the cation's formula? ________________

  What's the anion's charge? ___________

  What's the anion's formula? ________________

  What's the cation:anion ratio? ________________

  What's the ionic compound's formula? _____________________

- ammonium perchlorate

  What's the cation's charge? ___________

  What's the cation's formula? ________________

  What's the anion's charge? ___________

  What's the anion's formula? ________________

What's the cation:anion ratio? ________________

What's the ionic compound's formula? _____________________

In this example, both the cation and the anion are polyatomic ions. This happens.

By the way, ammonium perchlorate is one of the things they use in booster rockets such as for the space shuttle. Hundreds of tons of the stuff were used in each shuttle booster. Massive firepower: once ignited, those boosters could not be shut down.

‣ mercury(I) fluoride

What's the cation's charge? ___________ (Careful! Polyatomic!)

What's the cation's formula? ________________

What's the anion's charge? ___________

What's the anion's formula? ________________

What's the cation:anion ratio? ________________

What's the ionic compound's formula? _____________________

This example uses mercury(I) cation, which you simply have to remember is diatomic and not monatomic. There are a few other cases of transition metal diatomic cations, but we won't worry about those here.

‣ aluminum oxalate

What's the cation's charge? ___________

What's the cation's formula? ________________

What's the anion's charge? ___________

What's the anion's formula? ________________

What's the cation:anion ratio? ________________

What's the ionic compound's formula? _____________________

This one is a bit tricky. It has the polyatomic anion oxalate, $C_2O_4^{2-}$, and it needs parentheses. The formula is also a 2:3 ratio which can be one of the more confusing ones to derive. So, here's the clue which I mentioned above. Consider the charge numbers for the cation and the anion. The correct ion ratio for the formula is the <u>opposite</u> of the relative charge numbers. The charge numbers here are 3(+) and 2(−). The ion ratio is the opposite of that, 2:3. Thus, your final answer is $Al_2(C_2O_4)_3$.

You can actually use this clue on any combination whatsoever, such as 1:1, 1:2, etc. cases. You must note, however, that this method gives you the correct ratio of ions but your final answer must show that ratio in smallest whole numbers. For example, consider the prior example of tin(IV) sulfide. The charge numbers are 4(+) and 2(−), and the opposite gives the ion ratio, 2:4. You cannot write the final answer as Sn_2S_4, however, because you need smallest whole number ratio. Thus, you must take this to SnS_2 in the end.

This ends the naming of ionic compounds. Now we start into naming certain covalent compounds. You'll be happy to know these are much easier than ionics.

4.4 Binary covalent compounds

New word: binary. It means being composed of two different elements. That's two and only two different elements. There can be <u>any</u> number of total atoms, but they must all be from two elements. The word applies to any kind of compound whatsoever: covalent or ionic, molecular or network. Any compound, as long as it is composed of two elements. H_2O, HCl, NH_3, N_2O, SiO_2, SF_6, NaCl, K_2O, $AlCl_3$, etc. They're all binaries.

Warning! Many people confuse "binary" with "diatomic" because both involve two of something. Bad move. You must remember the distinction. Binary involves two elements, any number of atoms. Diatomic involves two atoms of the same or different elements. Something can be binary, diatomic, both or neither. H_2O is binary but not diatomic. Cl_2 is diatomic but not binary. HCl is both binary and diatomic. $C_{12}H_{22}O_{11}$ is none of these.

Why do we need this new word right now? It's because covalent compounds include so many different kinds of compounds that one naming system cannot work. Several naming systems exist just for the different kinds. The naming system for binary covalent compounds is the easiest and encompasses many, important compounds for our purposes. This is the one we use now for covalents. Unfortunately, it's also one of the oldest, which means some of the old traditions and exceptions have been carried into current usage.

Most of the binary covalent compounds involve metalloid and nonmetal elements bonded together in molecules or in a network. Everything here is neutral; there are no ions whatsoever. The name of the compound consists of two words derived from the names of the two elements involved. The first word of the name is the name of the first element in the formula. The second word of the name is the root name of the second element followed with the suffix *-ide*. In addition, each word of the name contains a numerical prefix to indicate the number of atoms in the formula. Well, almost. There are two exceptions to this but I want to list the numerical prefixes first.

mono- There's one of these atoms in the formula.
di- There're two of these atoms in the formula.
tri- Three.
tetra- Four.
penta- Five.
hexa- Six.
hepta- Seven.
octa- Eight.
nona- Nine.
deca- Ten.

Yes, they go higher but those numbers aren't very useful for our purposes. As a matter of fact, *hepta-*, *octa-*, and *nona-* aren't either. The others are fairly common for the compounds which you might typically encounter in a first-year course.

OK, I said there were exceptions to the prefixes. Remember that this is an old naming system with some strange carryovers. First, "hydrogen" does not take a prefix. Why? I don't know, but that's the way it is. Second, the use of the prefix *mono-* is optional. It's not used at all for the first word of the name. It is used for the second word of the name but not every time. Why? Some people do and some people don't. That's all I can tell you. Just know that the prefix *mono-* means one and that no prefix at all means one. Although it's optional, your instructor may require a certain way. Follow that way.

Because hydrogen does not take a numerical prefix, the name will not directly tell you how many are in the formula. So "hydrogen chloride" could be HCl, H_2Cl, H_3Cl, etc. How to know? Well, this is where there's an overlap with the ionic system. Pretend that the compound is ionic and that each H is H^+. How many does it take for neutrality? In this example, chloride would be 1−, so neutrality requires a one-to-one ratio. The formula is therefore HCl. Remember, however, that this ionic business is just pretense. The compound HCl is a binary covalent compound. It is not ionic. The overlap of the naming systems is a historical carryover.

OK, here goes. We begin again with formula-into-name.

- SF_6
  The first element is sulfur. One sulfur is indicated in the formula, so no prefix is used. The second element is fluorine and the word gets changed to fluoride. Six are indicated in the formula so the prefix *hexa-* is added. The full name is sulfur hexafluoride.

- N_2O
  The first element is nitrogen. Two are indicated in the formula, so the prefix *di-* is added. The second element is oxygen and the word gets changed to oxide. One is indicated in the formula so the prefix *mono-* may be used but it is not required. The full name is dinitrogen oxide or dinitrogen monoxide.

Notice that, when mono and oxide are combined, one of the middle o's is dropped. Otherwise it would be monooxide.

By the way, N_2O is laughing gas. Fairly gentle. They use it as an anesthetic, especially in dentistry. They've been using it that way since 1844. It's also the common propellant in cans of whipped cream. It's on the label, although the companies sometimes call it nitrous oxide. Same stuff.

- H_2S
  The first element is hydrogen. Hydrogen does not take a numerical prefix at all. The second element is sulfur and the word gets changed to sulfide. One is indicated in the formula so the prefix *mono-* may be used but it is not required. The full name is hydrogen sulfide. You could call it hydrogen monosulfide but most people don't.

This stuff smells really wretched and it is very deadly. It's one of the few compounds on Earth that humans can smell at the extremely low concentration of parts-per-billion range. Believe me, that's very little.

Alright, your turn again. We'll work through two examples.

- B_2Br_4

  What is the name of the first element? ______________________

  Does it take a numerical prefix? If yes, what is it? ________________

  What is the name of the second element? ______________________

  Change the ending. ______________________

  Does it take a numerical prefix? If yes, what is it? ________________

  What is the full name of the compound? _____________________________________

- PCl_5

  What is the name of the first element? ______________________

  Does it take a numerical prefix? If yes, what is it? ________________

  What is the name of the second element? ______________________

  Change the ending. ______________________

  Does it take a numerical prefix? If yes, what is it? ________________

  What is the full name of the compound? _____________________________________

  That ends this part. Now, reverse the translation direction: go names into formulas.

- boron nitride
  The first element is boron; there is no numerical prefix so that means one B is in the formula. The second element is nitrogen, as indicated by nitride. There is no numerical prefix so that means that one N is indicated in the formula. The formula is BN.

This is the covalent network compound which I had mentioned early in this Chapter. Now consider this: how can you tell whether something is a covalent network compound or just a molecular compound, based only on the name or formula? You can't. So don't bother trying.

- tetraphosphorus decaoxide
  The first element is phosphorus. The numerical prefix is *tetra-* so that means four P's are indicated in the formula. The second element is oxygen, as indicated by oxide. The numerical prefix is *deca-* so that means that ten O's are indicated in the formula. The formula is P_4O_{10}.

By the way, "decaoxide" has two middle vowels; as in the case of "monooxide" earlier, decaoxide often drops the first of those two vowels and is written as decoxide. This goes for other prefixes, too: for example, four oxygens could be written tetraoxide or tetroxide.

- carbon diselenide

  The first element is carbon. There is no numerical prefix so that means one C is in the formula. The second element is selenium, as indicated by selenide. The numerical prefix is *di-* so that means that two Se's are indicated in the formula. The formula is CSe_2.

  Alright, your turn again. We'll work through two examples.

- arsenic trifluoride

  What is the first element's symbol? ___________

  How many are indicated in the formula? ___________

  What is the second element's symbol? ___________

  How many are indicated in the formula? ___________

  What is the formula of the compound? ______________________

- nitrogen oxide

  What is the first element's symbol? ___________

  How many are indicated in the formula? ___________

  What is the second element's symbol? ___________

  How many are indicated in the formula? ___________

  What is the formula of the compound? ______________________

This compound could also be named nitrogen monoxide.

This last example is another N/O binary covalent compound, in addition to N_2O earlier. Interestingly, nitrogen and oxygen give quite an assortment of binary covalent compounds. These serve to illustrate the importance of identity of the chemical unit and the importance of correct names and formulas. Let's take a look at three of them at this time: N_2O and NO, our examples above, and NO_2. All consist of covalent, binary molecules.

N_2O, dinitrogen oxide
Harmless at reasonable concentrations. Used as an anesthetic.
NO_2, nitrogen dioxide
Very harmful. It is generated in vehicle exhaust and contributes to pollution.
NO, nitrogen oxide
Very harmful. It is also generated in vehicle exhaust and contributes to pollution.

Now here's a kicker: in recent decades, they've realized that NO is actually produced in biological tissues. In fact, it is essential to humans in tiny amounts. That's another example of the many twists of Nature: a compound which is deadly in small amounts, but absolutely essential in tiny amounts! Studies of NO are hugely important in many areas of medical research lately.

This ends my little N/O comparison. Again, the point was to emphasize the importance of identity of the chemical unit and the importance of correct names and formulas.

4.5 We're done. Almost.

A few closing remarks, a few details and a few pointers.

Names and formulas can be tedious to get used to, but it is essential. I know it will take a while, but you must practice. Do some examples and then do more examples. Learn it.

And learn it right. That includes spelling. I know spelling details can be a nuisance but one letter can mean an entirely different chemical unit. Chlorine versus chloride. Chloride versus chlorite. Chlorite versus chlorate. They're all different. You might think that being one letter off is just a little spelling error. In chemistry, it could mean the wrong compound completely. Would you rather use sodium chloride or sodium chlorite on your food? That "little spelling error" could hurt you big time.

Practice. Practice. Practice.

At this point in learning chemistry, there is one more catch to using these two naming systems. The catch is, which system do you use? If you're given a formula and told to name the compound, do you give it an ionic name or do you give it a covalent name? Your first task is to distinguish whether the compound is ionic or covalent. I recommend two guidelines.

1. If the formula starts with a metal element or with NH_4... (or other polyatomic cation), then assume the compound is ionic. Use the ionic compound rules.
2. Assume other compounds are covalent. Use the binary covalent rules.

These are guidelines. There are exceptions, but they're good enough for now. Notice that you need to know who is a metal element again. That's another job for using PoBiSnAl with the Periodic Table. Let me illustrate these guidelines with an application: give the names for $AlCl_3$ and $SiCl_4$.

$AlCl_3$ starts with a metal element and so we assume it's ionic. The name is based on the ionic system, so the name is aluminum chloride.

$SiCl_4$ does not start with a metal element and so we assume it is covalent. The name is based on the binary covalent system, so the name is silicon tetrachloride.

4.6 Other systems

There remain other name systems for other classes of compounds. We will do one for acid compounds in Chapter 12. I am postponing it until we talk more about acids in general. Your instructor might include it here, so you can go to that part and check it out if you want to (or need to). It's Section 12.1; I wrote that Section so you could do it from here.

There is another naming system for hydrates which is only a small variation to what I've covered here. Hydrates are compounds which have one or more molecules of water in their formula unit, in addition to an ionic portion or another covalent portion. For example, $CuSO_4$ is an ionic compound while $CuSO_4 \bullet 5\ H_2O$ is an ionic hydrate. BF_3 is a covalent compound while $BF_3 \bullet H_2O$ is a covalent hydrate. Some instructors cover the naming for these compounds while other instructors do not. Basically, the word "___hydrate" is added to the name, where the underline contains a numerical prefix for the number of water molecules in the formula unit. Thus, $CuSO_4 \bullet 5\ H_2O$ is named copper(II) sulfate pentahydrate and $BF_3 \bullet H_2O$ is named boron trifluoride monohydrate. Some hydrate compounds are fairly common but I won't do much more with the hydrate names. Be aware if your instructor is including these names in your need-to-know coverage or not.

There's another system which is based on compounds of C and H, and which extends to compounds of C, H and a host of other elements. This system is very different. It is usually covered extensively in the second year of chemistry, but parts of it are sometimes found in first year courses. Your instructor may or may not include it. I will give three compounds here for illustration purposes.

methane, CH_4 propane, C_3H_8 butane, C_4H_{10}

Although these are binary covalent compounds, their names are instead covered by that other system. That's why their names don't look like anything I covered above. I chose these three compounds as examples because they are quite common to your world. All are fuels. Methane is produced naturally in massive amounts and its release to the air can add to atmospheric warming. It's also a major component of natural gas. Propane is the fuel used in small torches and in gas grills. Butane is the fuel in lighters.

Beyond the systems cited so far, there are some compounds which are very common but whose common names are not covered by any of the systems here. The most obvious example is water. Yes, chemists call it water and we don't call it hydrogen oxide or hydrogen monoxide. Another is ammonia, NH_3. Ammonia by itself is a gas but it dissolves really well in water. The water solutions are used as a cleaner and these are what is sold in the stores. You probably know the smell, but you don't want to know it too well. A strong smell can irritate the respiratory tract and can kill at high amounts. Another common compound is hydrogen peroxide, H_2O_2. That's what it's called, even though the binary covalent rules say it should be hydrogen dioxide. Hydrogen peroxide is used in a lot of applications as a bleaching agent and as a mild disinfectant when dilute. You can buy it in the store dissolved in water; the solutions are typically 3% H_2O_2 and the rest is mostly water. It's also in a bunch of other products such as hair dye products, toothpastes, etc. It's on the labels. Read them. You wouldn't want to get near the pure compound, because it likes to blow up without warning. It's been used in rocket engines. There are still other common compounds whose names and formulas don't fit the systems presented here. Your instructor may require you to memorize some of these. Be aware if that applies.

OK, so much for other classes of compounds. Before closing out this Chapter, let me mention two older naming systems which have been around a long time and don't die easily. These apply to ionic compounds and binary covalent compounds, although these systems have been abandoned by chemists in recent decades in favor of the systems which I described above. I mention them here because the old names still creep in sometimes, especially in commercial or industrial applications. This means that many of the labels on the goods in stores will list ingredients by those older methods.

One of the oldie systems uses the binary covalent system to name an ionic compound. For example, consider PbO_2 which is used in vehicle (lead) batteries. The correct chemistry name is lead(IV) oxide, but you will still hear it called lead dioxide. Another example is TiO_2. This compound is one of the most widely used white pigments and it's just about everywhere these days. It's in white or light-colored paints; it's in finer paper; it's in plastics; it's even found its way into some grocery products. The correct chemistry name is titanium(IV) oxide, but it still shows up on many labels as titanium dioxide.

A second oldie system used *-ous* and *-ic* endings. This system was popular for a very long time but it became too cumbersome to sustain as more and more compounds were discovered and identified. But it still finds use in your world. I mentioned one example above when I said dinitrogen oxide (N_2O) is still called nitrous oxide commercially. What I didn't tell you above is that nitrogen oxide (NO) is sometimes called nitric oxide. These illustrate the *-ous* and *-ic* endings in covalent compounds, but *-ous/-ic* endings were also used for ionic compounds as endings for variable charge cations. The endings followed the root of the element's symbol name. For iron, the symbol is Fe from ferrum (Latin). So Fe^{2+} was called ferrous ion; Fe^{3+} was called ferric ion. For gold, the symbol is Au from aurum. Au^{+} was called aurous ion; Au^{3+} was called auric ion. Some names were normal. Co^{2+} was cobaltous ion; Co^{3+} was cobaltic ion. Another problem was that, for some elements, the charges were 2+ for "*-ous*" and 3+ for "*-ic*"; for some other elements, the charges were 2+ for "*-ous*" and 4+ for "*-ic*"; for some other elements, the charges were 1+ for "*-ous*" and 2+ for "*-ic*"; and, for even other elements, the charges were 1+ for "*-ous*" and 3+ for "*-ic*". Confused? This system could be a nightmare. It's still used in many industrial and commercial products. If you see an ingredient on a label with an *-ous* or *-ic* ending and you can't figure it out, you can check a reference book or ask your instructor for the correct chemistry formula and name.

Problems

1. True or false.
   a. Sulfur dioxide is a covalent compound.
   b. Carbon monoxide is diatomic and binary.
   c. Solid potassium fluoride is an ionic network.
   d. AsH_3 is ionic.
   e. Nitrate is composed of N^{3-} and O^{2-} ions.
   f. Propane is one allotrope of carbon.

2. True or false.
   a. Bisulfite is a hydrogen anion and it has a charge of 1– .
   b. Chlorine dioxide is a binary, covalent compound.
   c. BF_3 consists of a B^{3+} cation and F^{-} anions.
   d. Bicarbonate is a polyatomic ion of 2– charge.
   e. Oxalate has a charge of 3–.
   f. Lithium fluoride has covalent bonds.

3. True or false.
   a. The bonds within the hydrogen carbonate ion are covalent.
   b. Chromate is an oxyanion.
   c. Magnesium sulfide is composed of Mg^{2+} and S^{2-} ions.
   d. Selenium oxide is composed of Se^{2+} and O^{2-} ions.
   e. Hydrogen phosphate anion carries a 2– charge.
   f. Ammonia is a binary compound.

4. Which of the following compounds have a 1+ cation?

   HCl KNO_3 $CuSO_4$ NH_4F IBr S_2O

5. Which of the following compounds are covalent?

   CsF SiO_2 ClF_3 CuO $Ca(OH)_2$ B_2H_6

6. Which of the following compounds have an anion of 2– charge?

   K_2O H_2Se $CaCO_3$ $HgCl_2$ SO NH_4NO_3

7. a. What is the charge of the barium ion?
   b. What is the charge of the dihydrogen arsenate anion?
   c. What is the charge of the sulfide ion?

8. a. How many electrons are in the lithium ion?
   b. How many electrons are in the cobalt(II) ion?
   c. What is the charge of the chlorite ion?

9. a. How many electrons are in the chloride ion?
   b. How many electrons are in the gold(I) ion?
   c. What is the charge of the acetate ion?

10. Give the formula for each of the following.
    a. gold(I) iodide
    b. butane
    c. potassium chromate
    d. nitrogen triiodide

11. Give the formula for each of the following.
    a. diselenium hexasulfide
    b. nickel(III) nitrate
    c. hydrogen peroxide
    d. sodium hydrogen carbonate

12. Give the formula for each of the following.
    a. sulfur trioxide
    b. cobalt(III) sulfate
    c. sodium nitrite
    d. aluminum oxide

13. Give the formula for each of the following.
    a. phosphorus pentachloride
    b. lithium hydride
    c. barium acetate
    d. iron(III) cyanide

14. Give the name for each of the following.
    a. Li_3N b. $Cr(ClO_4)_3$ c. SiO_2 d. CH_4

15. Give the name for each of the following.
    a. ClF_3 b. NH_4HSO_4 c. Cu_2SO_3 d. $Hg_2(NO_3)_2$

16. Give the name for each of the following.
    a. FeC_2O_4 b. K_3PO_4 c. PbO_2 d. S_2Cl_2

17. Give the name for each of the following.
    a. H_2S b. CaS_2O_3 c. NO_2 d. $Mn(ClO_3)_3$