What's in a Name?
The Nomenclature of Inorganic Compounds

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Key Concepts

- Name a compound starts with the names of the ions.
  - Names of simple cations
  - Names of simple anions
  - Names of polyatomic cations and anions
- Classifying compounds into one of the 3 categories.
  - Ionic Compound (compounds that either contain metallic atoms or polyatomic ions).
  - Covalent Compound (compounds that consist of nonmetallic atoms only).
  - Inorganic Acids (compounds that consist of proton(s) bonded to simple anions or polyatomic anions).
- Steps of Naming simple inorganic compounds

Related Tutorials

- *Molecular Representations*
- *Naming Coordination Compounds*

The Cautionary Tale of Dihydrogen Monoxide…

The following is an excerpt from an article in *Natural History* 5/98 by Neil de Grasse Tyson:

> Nathan Zohner, a student at Eagle Rock Junior High School in Idaho, conducted a clever science-fair experiment that tested anti-technology sentiments and associated chemical phobias in 1997. He invited people to sign a petition that demanded either strict control of, or a total ban on, dihydrogen monoxide. He listed some of the odious properties of this colorless and odorless substance:
> 1. It is a major component of acid rain.
> 2. It eventually dissolves nearly anything it comes into contact with.
> 3. It is lethal if accidentally inhaled.
> 4. It can cause severe burns in its gaseous state.
> 5. It has been found in tumors of terminal cancer patients.
>
> Forty-three out of fifty people approached by Zohner signed the petition, six were undecided, and one was a strong supporter of dihydrogen monoxide and refused to sign. Yes, 86% of the passersby voted to ban water (H_2O) from the environment.

We live in a world made of chemicals. Table salt is sodium chloride; sugar is a disaccharide; a major ingredient of vinegar is acetic acid; glass is a super-cooled liquid silicate; our stomach contains 1 M hydrochloric acid. As you can see, it is important to be able to recognize a chemical by its name. In this tutorial, you will learn about the systematic naming of inorganic compounds.

Naming Simple Cations

Monatomic cations bear the same names as their elements, with the addition of the word 'ion'. Many elements (such as sodium and calcium) have only one stable form of cations in solution. Hence, Na^{+} is called the sodium ion, and Ca^{2+} is called the calcium ion. Na^{2+} and Ca^{+} ions are not stable in solutions. Notice that if you refer to the periodic chart, with no exception, the stable ion of all the Group IA metals (**alkali metals**) have a +1 charge, and the Group IIA metals (**alkaline earth metals**) have a +2 charge. This is due to the ground-state electron configurations of these elements, a topic you will learn about in the Chem 111A lectures in the near future. Other common metal cations that have only one stable oxidation state are: Al^{3+}, Ga^{3+}, Ni^{2+}, Zn^{2+}, Cd^{2+}, and Ag^{+}. Some of the cations that have only one stable form are listed in Table I.

Table I

Li^{+} lithium ion	Be^{2+} beryllium ion	Al^{3+} aluminum ion
Na^{+} sodium ion	Mg^{2+} magnesium ion	Ga^{3+} gallium ion
K^{+} potassium ion	Ca^{2+} calcium ion	
Rb^{+} rubidium ion	Sr^{2+} strontium ion	
Cs^{+} cesium ion	Ba^{2+} barium ion	
Fr^{+} francium ion	Ra^{2+} radium ion	
Ag^{+} silver ion	Ni^{2+} nickel ion	
Zn	$^{2+}$ zinc ion	
Cd	$^{2+}$ cadmium ion	

Some metals, especially the transition metals (with a few exceptions that are printed in blue in Table I), can form more than one type of cation, such as Fe^{2+} and Fe^{3+} or Cu^{+} and Cu^{2+}. To distinguish between these ions, there are two naming systems. The old style system has different suffixes in their names. For example, Fe^{2+} is called the ferrous ion, and Fe^{3+} is called the ferric ion; Cu^{+} is the cuprous ion, and Cu^{2+} is the cupric ion. Notice that the ion with the lesser charge ends with –ous and the one with greater charges ends with –ic. In contrast, the systematic naming method used today indicates the charge of the ion with a Roman numeral in parentheses (called the Stock number) immediately following the ion's name. Thus, Fe^{2+} is an iron(II) ion and Pb^{4+} is a lead(IV) ion. Ca^{2+} is just calcium ion, not calcium(II) ion, because calcium only has one kind of stable cation. The names of some simple cations are listed in Table II.

Table II

Element	Cation	Systematic Name	Old Style Name
Cobalt Co	$^{2+}$	Cobalt(II) ion	Cobaltous ion
Co	$^{3+}$	Cobalt(III) ion	Cobaltic ion
Copper Cu	$^{+}$	Copper(I) ion	Cuprous ion
Cu	$^{2+}$	Copper(II) ion	Cupric ion
Iron Fe	$^{2+}$	Iron(II) ion	Ferrous ion
Fe	$^{3+}$	Iron(III) ion	Ferric ion
Lead Pb	$^{2+}$	Lead(II) ion	Plumbous ion
Pb	$^{4+}$	Lead(IV) ion	Plumbic ion
Mercury Hg	$_2^{2+}$	Mercury(I) ion*	Mercurous ion
Hg	$^{2+}$	Mercury(II) ion	Mercuric ion
Tin Sn	$^{2+}$	Tin(II) ion	Stannous ion
Sn	$^{4+}$	Tin(IV) ion	Stannic ion

* Despite the +2 charges, each Hg in the Hg_2^{2+} ion only carries a charge of +1 (the oxidation number is +1). This is why it is called mercury(I) ion.

Naming Simple Anions

Monatomic anions are named by adding the suffix -ide to the stem of the name of the nonmetallic elements from which the anion is derived. For example, Cl^- is called chloride and S^{2-} is called sulfide. Like a cation, the charge carried by an anion is related to the ground-state electron configuration of the element and thus is related to the position of the element in the periodic chart. All the halogen anions (they are called halide ions) carry a −1 charge because the halogen group is one group to the left of the noble gases in the periodic chart. The oxide and sulfide ions carry a −2 charge because they are located two groups away from the noble gases in the periodic chart. Following this logic, one can predict that the nitride ion and the phosphide ion must carry a −3 charge. Some of the simple anions and their names are listed in Table III. The hydride, peroxide, superoxide, and carbide ions (shown in blue) are exceptions to the above rule.

Table III

F^- fluoride ion	O^{2-} oxide ion	N^{3-} nitride ion
Cl^- chloride ion	S^{2-} sulfide ion	P^{3-} phosphide ion
Br^- bromide ion	Se^{2-} selenide ion	
I^- iodide ion	O_2^{2-} peroxide ion	
H^- hydride ion	C_2^{2-} carbide ion	
O_2^- superoxide ion		

Naming Polyatomic Ions

Some of the names and charges of common polyatomic cations and anions are listed in Table IV.

Table IV

Cations		Anions		
+1	**+2**	**−1**	**−2**	**−3**
NH_4^+ ammonium	VO^{2+} vanadyl	OH^- hydroxide		
H_3O^+ hydronium		CN^- cyanide	CrO_4^{2-} chromate	
NO^+ nitrosyl		MnO_4^- permanganate	$Cr_2O_7^{2-}$ dichromate	
		NO_2^- nitrite	SO_3^{2-} sulfite	AsO_3^{3-} arsenite
		NO_3^- nitrate	SO_4^{2-} sulfate	AsO_4^{3-} arsenate
		ClO^- hypochlorite		
		ClO_2^- chlorite		
		ClO_3^- chlorate		
		ClO_4^- perchlorate		
		HCO_3^- bicarbonate or hydrogen carbonate	CO_3^{2-} carbonate	
		$H_2PO_4^-$ dihydrogen phosphate	HPO_4^{2-} hydrogen phosphate	PO_4^{3-} phosphate
		CH_3COO^- acetate	$C_2O_4^{2-}$ oxalate	

Notice that there are a lot more polyatomic anions than cations. Most polyatomic anions consist of a nonmetallic element combined with different numbers of oxygen atoms (these polyatomic anions are called **oxoanions**). Even though it seems that there is no simple rule in naming these ions, in fact, here are some guidelines to follow:

- When an element forms two different oxoanions, the ion with the lesser number of oxygen atoms ends with –ite, and the one with more oxygen atoms ends with –ate. Examples are the ions in blue in Table IV.

- When an element forms more than two oxoanions, the prefixes hypo– and per– are used to indicate the one with the fewest number of oxygens and the most number of oxygens, respectively. Examples are the oxoanions of the halogens (in orange in Table IV). Similarly, BrO_4^- is called perbromate ion and IO^- is called hypoiodite ion.
- When H^+ is added to an oxoanion, the name of the hydrogen-containing polyatomic anion begins with the word 'hydrogen' or 'dihydrogen'. An older but still commonly used naming system is to add the prefix bi– to denote the presence of hydrogen. Examples are the ions in green in Table IV.

It should be noted that the acetate and oxalate ions (in purple) are organic ions. They follow the naming system of organic compounds. They are included for reference here, as they are commonly used in Chem 111A, 112A, 151 and 152.

Elements in the same group of the periodic chart have similar chemical properties; hence, they often form similar polyatomic ions. Therefore, if we know the name and formula for a particular polyatomic ion, then by analogy, we can determine the name and formula of the similar polyatomic ion of another element in the same group. For example, if one knows that chlorate ion is ClO_3^-, then, an educated guess for the formula of bromate ion is BrO_3^- and for iodate ion is IO_3^-.

It is important to know the names of polyatomic ions, and it is equally important to be familiar with their size and shape. Click "*Molecular Representations*" to see 2D and 3D representations of some of the ions from table IV and to learn about how molecules are often represented in chemistry and biology.

Naming Compounds

For the purpose of nomenclature, the inorganic compounds can be separated into 4 categories.

I. Compounds of high ionic character ---- Two types of compounds fall into this category: 1. those consisting of a metal combined with a nonmetal (e.g., NaCl, Ag_2S, PbO) and 2. compounds containing polyatomic ions, except for the oxoacids (e.g., $CaSO_4$, NH_4NO_3, KCN, but excluding H_2SO_4, HNO_3, etc.). For the sake of naming compounds, both of these categories will be classified as ionic compounds in this tutorial.

To name an ionic compound, one should name the cation first, and then name the anion (with the word 'ion' omitted). It is not necessary to indicate the number of cations and anions in the compound because it is understood that the total positive charges carried by the cations must equal the total negative charges carried by the anions. A few examples are listed below:

KI	potassium ion + iodide ion = potassium iodide
$CoCl_2$	cobalt(II) ion + two chloride ions = cobalt(II) chloride
$CoCl_3$	cobalt(III) ion + three chloride ions = cobalt(III) chloride
Hg_2Cl_2	mercury(I) ion + two chloride ions = mercury(I) chloride or mercurous chloride
$AgNO_3$	silver ion + nitrate ion = silver nitrate It is not called silver(I) nitrate because Ag^+ is the only stable ion of silver.
$(NH_4)_2S$	two ammonium ions + sulfide ion = ammonium sulfide
$Al(HCO_3)_3$	aluminum ion + bicarbonate ion = aluminum bicarbonate or aluminum hydrogen carbonate

Some ionic compounds incorporate water molecules in their structure. These compounds are called hydrates. To name the hydrates, the number of waters of hydration is indicated by a Greek prefix following the name of the compound. For example, $CuSO_4 \cdot 5H_2O$ is called copper(II) sulfate pentahydrate.

Determining the molecular formula from the compound's name is not always straightforward. This is because the number of cations and anions in a molecule is not specified in the name of an ionic compound. The following examples show how finding the molecular formula can be achieved in a systematic matter:

Example 1. Give the molecular formula of aluminum sulfide.
Solution:

i) Since aluminum is a metal and sulfur is a nonmetal, this compound is classified as an ionic compound.
ii) The cation, aluminum ion, is: Al^{3+} (if you forget the charge of the aluminum ion, look up the position of Al in the periodic chart).
iii) The anion, sulfide, is: S^{2-} (the –ide suffix indicates that it is a simple anion).
iv) How many Al^{3+} ions should combine with the appropriate number of S^{2-} ions such that the molecule carries no net charge? Al_2O_3 is the answer.

Example 2. Give the molecular formula of vanadium(III) phosphate.
Solution:

i) You may not recognize that vanadium is a metal. However, the suffix –ate in the word 'phosphate' is the hint of an oxoanion, a polyatomic ion. You know that this compound is classified as an ionic compound.
ii) The cation is vanadium(III) = V^{3+}.
iii) The anion is phosphate = PO_4^{3+}.
iv) How many V^{3+} ions should combine with the appropriate number of PO_4^{3-} ions such that the molecule carries no net charge? VPO_4 is the answer.

Example 3. Give the molecular formula of ammonium sulfate.
Solution:

i) Both ammonium and sulfate are polyatomic ions. Again, this compound is classified as an ionic compound.
ii) The cation is ammonium ion = NH_4^+.
iii) The anion is sulfate ion = SO_4^{2-}.
iv) The molecular formula of the compound is $(NH_4)_2SO_4$ because it takes two groups of NH_4^+ to combine with one SO_4^{2-} ion to give a molecule that carries no charge.

Practice Problems (Answer key is located at the last page of this tutorial)

1. Name the following ionic compounds:

$Cr_2(SeO_4)_3$
$Sr(ClO)_2$
MnO_2
Na_2O_2

2. Give the chemical formulas for the following ionic compounds:

cobaltic nitrate
vanadium (V) oxide
magnesium dihydrogen phosphate
ammonium ferrous sulfate hexahydrate

II. Compounds of high covalent character---- Compounds consisting of only nonmetals and no polyatomic ions belong to this category (e.g., SO_2, NH_3, CS_2 but not NH_4Cl because NH_4^+ is a polyatomic cation). They will be called covalent compounds in this tutorial.

To name the covalent compounds, name the electropositive (or less electronegative) element first. Then, name the more electronegative element as if the more electronegative element is a simple anion (ending with –ide). How does one know which element is the electropositive element? In the chemical formulas of covalent compounds, usually the symbol of the electropositive element precedes the more electronegative element (e.g., SO_2, CO, and SF_6. NH_3 is an exception of this generalization.). If one follows this rule, then, SO_2 would be called sulfur oxide, and CO would be called carbon oxide. Very often, two nonmetals can combine to form more than one compound. For example, carbon and oxygen can combine to form CO_2 or CO; sulfur and oxygen can combine to form SO_2 or SO_3. To distinguish these compounds from each other, Greek prefixes are used to designate the numbers of atoms of one or both elements in the molecule. Therefore, CO_2 is called carbon dioxide and CO is called carbon monoxide; SO_2 is sulfur dioxide and SO_3 is sulfur trioxide.

Greek prefixes:

mono-	1	hexa-	6
di-	2	hepta-	7
tri-	3	octa-	8
tetra-	4	nona-	9
penta-	5	deca-	10

The following are a few examples:

NF_3 nitrog en trifluoride
N_2O_4 dinitrogen tetraoxide
OF_2 oxygen difluoride

For historical reasons, some hydrogen-containing covalent compounds have nonsystematic names such as:

H_2O water
NH_3 ammonia
PH_3 phosphine
N_2H_4 hydrazine
SiH_4 silane

Practice Problems (Answer key is located at the last page of this tutorial)

3. Name the following covalent compounds:

NO_2
NO
N_2O
P_4O_{10}

4. Give the chemical formulas for the following covalent compounds:

hydrogen sulfide
dinitrogen pentoxide

III. Inorganic acids ---- The rules used to name inorganic acids are different from those rules used to name the ionic and covalent compounds. For example, HNO_3 is called nitric acid, not hydrogen nitrate nor hydrogen nitrogen trioxide. How can one recognize an acid

by looking at its chemical formula? You will learn about the properties of acids in detail in the second semester of general chemistry. Here we will simply present the rules for naming acids. An acid is a proton donor. Therefore, for the purpose of nomenclature, an acid can be viewed as a molecule with one or more protons (H^+) bonded to an anion. Note that the molecule must not carry a charge. For example, HSO_3^- is not an acid molecule; it is an anion because it carries a −1 charge. Even though it shows acidic properties, it is named like a polyatomic anion. Also, the molecule must not contain metal atoms. For example, $NaHSO_3$ should not be named as an acid. Instead, it should be named as an ionic compound because it consists of a Na^+ cation and an HSO_3^- anion. Thus, it is named sodium bisulfite or sodium hydrogen sulfite.

Many acids consist of protons bonded to an oxoanion (e.g., HNO_3 is H^+ bonded to NO_3^- and H_2SO_4 is two H^+ ions bonded to a SO_4^{2-} ion). These acids are called **oxoacids**. To name an oxoacid, one should change the –ate or –ite suffixes of the oxoanions to –ic or –ous respectively and add the word acid at the end. For example,

HNO_3 is H^+ bonded to NO_3^- (nitrate), thus it is called nitric acid.
HNO_2 is H^+ bonded to NO_2^- (nitrite), thus it is called nitrous acid.

Besides the oxoacids, there are other acids in which the anions end with the suffix –ide. The names of these acids begin with hydro– and end with –ic. For example, aqueous HCl is called hydrochloric acid because the anion, Cl^-, is named chloride.

The names of the inorganic acids are closely related to the names of the anions in the acid. The correlations among the names of the anions and the names of the acids are summarized in Table V below with examples:

Table V

Name of Anion	Name of Acid	Examples
...–ide Hydro...	–ic acid	HCN(aq) cyanide → hydrocyanic acid HBr(aq) bromide → hydrobromic acid
Per ...–ate	Per…–ic acid	$HClO_4$ perchlorate → perchloric acid
...–ate	…–ic acid	$HClO_3$ chlorate → chloric acid H_2SO_4 sulfate → sulfuric acid
...–ite	...–ous acid	$HClO_2$ chlorite → chlorous acid H_2SO_3 sulfite → sulfurous acid
Hypo...–ite Hypo…	–ous acid	HClO hypochlorite → hypochlorous acid

Note: The gaseous HCl, HBr, H_2S, etc. do not bear the names of acids. They are named as covalent compounds. A compound that dissolves in water to form an acid is called an acid anhydride (acid without water). Only the aqueous solutions of acid anhydrides are named as acids. Therefore, HCl(g) is called hydrogen chloride while HCl(aq) is called hydrochloric acid; HCN(g) is called hydrogen cyanide while HCN(aq) is called hydrocyanic acid. The distinction in naming the anhydrides and the acids is not critical for oxoacids, because all their anhydrides are different molecules. For example, the anhydride of H_2SO_4 is SO_3, not gaseous H_2SO_4. Thus H_2SO_4 is always called sulfuric acid, not hydrogen sulfate.

Practice Problems (Answer key is located at the last page of this tutorial)

5. Name the following compounds/ions:

Na_3N
CaCr $_2O_7$
HI(aq)
H_2S(aq)
SeO_3
SO_3^{2-}

6. Give the chemical formulas for the following compounds/ions:
periodic acid
potassium superoxide
gallium arsenite
copper(I) sulfate
radium ion
ammonium hydrogen phosphate

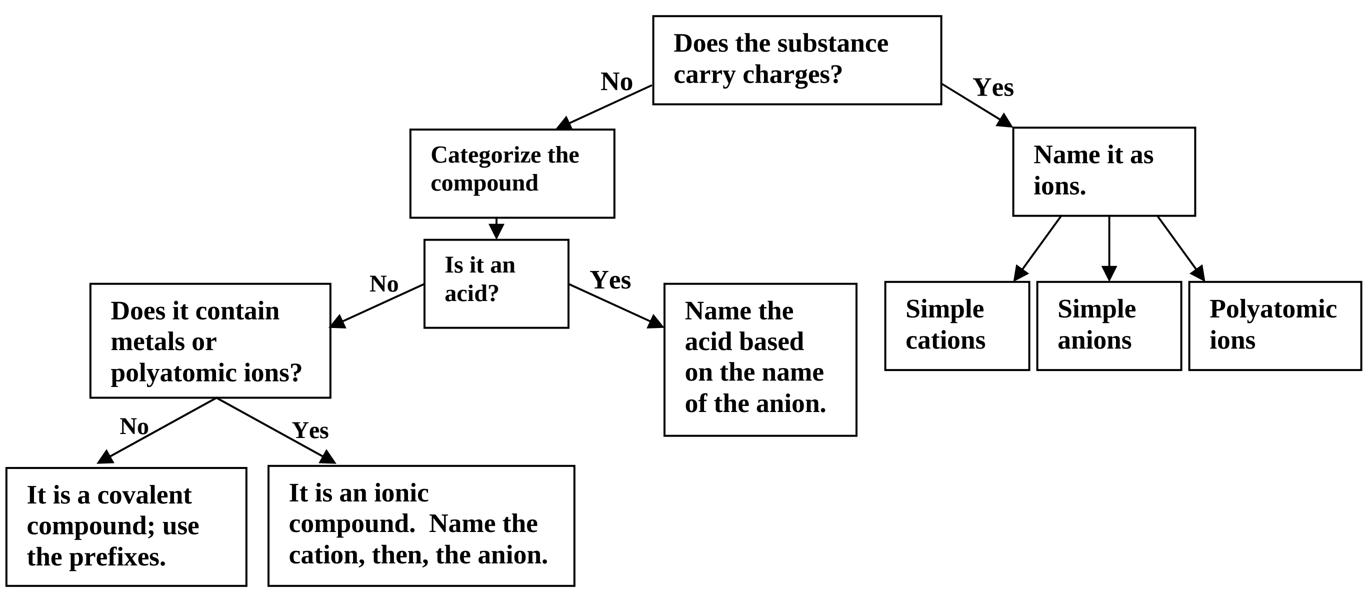
IV. Coordination compounds

Coordination compounds---- This family of compounds consists of central metal ion(s) bonded to molecules or anions called ligands. The nomenclature of these compounds will be discussed in this course in the near future. To learn more about this topic, please click "*Naming Coordination Compounds*".

Summary

Knowing the symbols and charges of the cations and anions is essential for the nomenclature of inorganic compounds. For the monoatomic ions, you can figure out the charges from the position of the element in the periodic chart. If the element is a transition metal that typically has more than one stable oxidation state, very often, the charge on the ion is indicated by the stock number (several exceptions such as Zn^{2+}, Cd^{2+} and Ag^{+}). For the polyatomic ions, one must spend more effort to get familiar with their formulas and charges.

The most important strategy in naming a chemical (or in predicting the formula from a given name) is to put it into the correct category. The following flow chart can help you categorize a chemical:



Acknowledgements:

The author thanks Regina Frey and Amy Walker for many helpful suggestions in the writing of this tutorial.

Revised July 2007

Answer to Practice Problems

1. Name the following ionic compounds:

$Cr_2(SeO_4)_3$ ***chromium(III) selenate*** *(Se and S are elements of the same group. Since SO_4^{2-} is called sulfate, an educated guess is to name the SeO_4^{2-} selenate.)*

$Sr(ClO)_2$ ***strontium hypochlorite***

MnO_2 ***manganese(IV) oxide*** *('manganese dioxide' is not a systematic name. The systematic naming method does not use prefixes in naming ionic compounds.)*

Na_2O_2 ***sodium peroxide*** *(sodium dioxide is incorrect because the anion is a peroxide anion, not an oxide anion.)*

2. Give the chemical formulas for the following ionic compounds:

cobaltic nitrate ***$Co(NO_3)_3$***

vanadium (V) oxide ***V_2O_5***

magnesium dihydrogen phosphate ***$Mg(H_2PO_4)_2$*** *dihydrogen phosphate is $H_2PO_4^-$*

ammonium ferrous sulfate hexahydrate ***$(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$***

3. Name the following covalent compounds:

NO_2 ***nitrogen dioxide***

NO ***nitrogen monoxide;*** *it is commonly called nitric oxide.*

N_2O ***dinitrogen monoxide;*** *it is also called nitrous oxide or laughing gas.*

P_4O_{10} ***tetraphosphorus decaoxide***

4. Give the chemical formulas for the following covalent compounds:

hydrogen sulfide ***H_2S*** *(It is not called dihydrogen sulfide because it takes two H^+ to combine with one S^{2-} to make an electrically neutral molecule. No other combination is possible.)*

dinitrogen pentoxide ***N_2O_5***

5. Name the following compounds/ions:

Na_3N ***sodium nitride***

$CaCr_2O_7$ ***calcium dichromate***

$HI(aq)$ ***hydroiodic acid***

$H_2S(aq)$ ***hydrosulfuric acid***

SeO_3 ***selenium trioxide***

SO_3^{2-} ***sulfite ion*** *(It is not sulfur trioxide because it is an anion.)*

6. Give the chemical formulas for the following compounds/ions:

periodic acid ***HIO_4*** *(Read the name as per-io-dic acid)*

potassium superoxide ***KO_2*** *(the cation is K^+ and the anion is O_2^-)*

gallium arsenite ***$GaAsO_3$***

copper(I) sulfate ***Cu_2SO_4*** *(It takes two Cu^+ to go with one SO_4^{2-})*

radium ion ***Ra^{2+}***

ammonium hydrogen phosphate ***$(NH_4)_2HPO_4$*** *(NH_4^+ cation and HPO_4^{2-} anion)*

Molecular Representations and Tables of Common Polyatomic Ions

Graphical computer modeling has greatly improved our ability to represent three-dimensional structures. One of the goals of graphical computer modeling is to create a computer-generated model that appears to be three-dimensional. By replicating the effect of light on three-dimensional objects, computers can give the impression of depth to simulate a three-dimensional appearance. The use of interactive molecular viewing (*e.g.,* using the Chime program) has enhanced our understanding of molecular structure, especially in the biochemical area. By interactively rotating the molecules, a clear picture of the three-dimensional structure emerges. In addition, this increases our chemical intuition because it teaches us to look at two-dimensional images and visualize their three-dimensional structure in our brains.

This course uses different types of structural representations, such as **2D-ChemDraw, stick, CPK, and ribbon,** to illustrate the structure of molecules and macromolecules. PDB files are also available for viewing the molecules interactively. Figure 1 is a segment of an alpha helix polypeptide string shown in four different types of computer-generated molecular representations. Although all four representations depict the same molecule, each has a distinct appearance and offers different information about the molecule's structure.

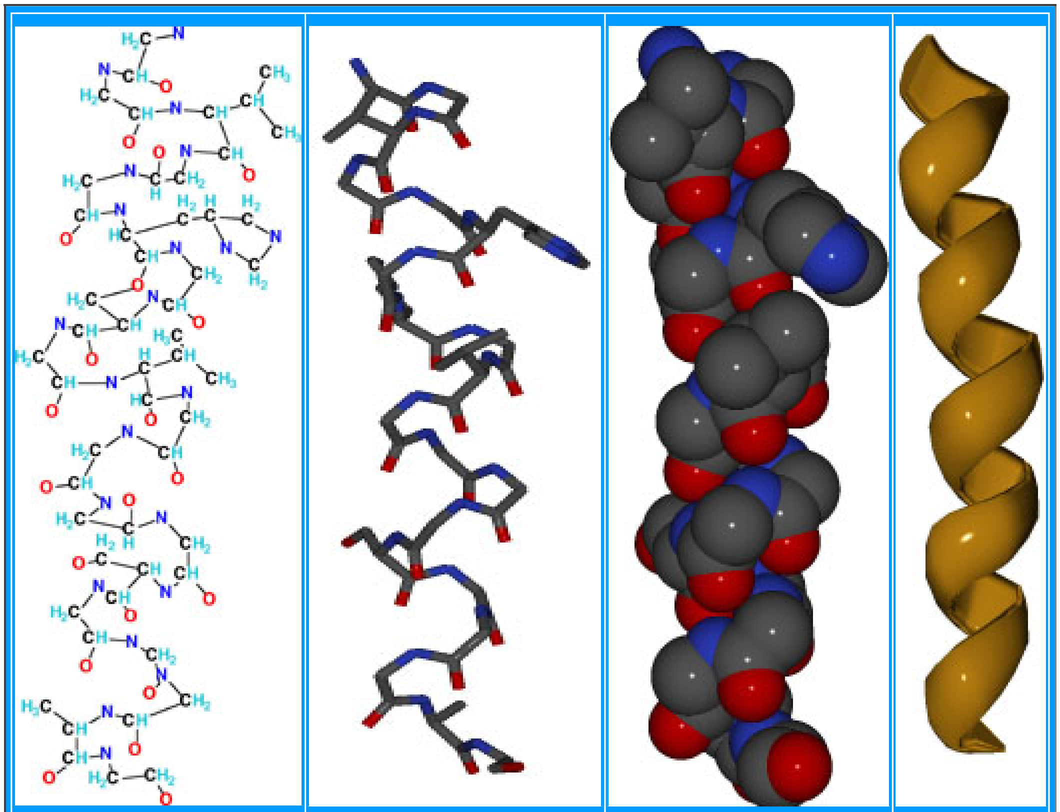


Figure 1 A segment of an alpha helix

The representations from left to right are 2D-ChemDraw, stick, CPK, and ribbon models. In the 2D-ChemDraw, stick, and CPK representations, carbon atoms are shown in gray (black), nitrogen atoms are shown in blue, and oxygen atoms are shown in red. In this figure, hydrogen atoms (light blue) are shown in the 2D-ChemDraw representation but hydrogen atoms are not shown in the other representations.

By examining the four representations in Figure 1, you can see that each picture tells us something different about the structure of the molecule. For instance, if we wanted to know how the atoms in an alpha helix are connected to one another, we would use 2D-ChemDraw or stick representation. To see the relative sizes of the atoms in an alpha helix, we would use the CPK (or space-filled) representation. Descriptions of the four types of representations, their major strengths, and their drawbacks are given in the table below.

Type of Representation	Description of Representation	Information Depicted Particularly Well by Representation	Drawbacks of Representation
2D-ChemDraw	Shows labeled atoms and bonds connecting atoms in a flat representation.	Shows connectivities between atoms in small molecules; can also include lone pairs (i.e., Lewis-dot structures).	Difficult to interpret for larger molecules; does not give a good idea of the molecule's three-dimensional structure.
STICK	Shows the bonds between atoms as three-dimensional "sticks" that are often color-coded to show atom type.	Shows connectivities between atoms; gives some idea of the molecule's three-dimensional shape.	Does not depict the size (volume) of the molecule or its constituent atoms, and hence gives a limited view of the molecule's three-dimensional shape.
CPK[1]	Shows atoms as three-dimensional spheres whose radii are scaled to the atoms' van der Waals radii.	Shows the relative volumes of the molecule's components; usually a good indicator of the molecule's three-dimensional shape and size.	Difficult to view all atoms in the molecule and to determine how atoms are connected to one another.
RIBBON	Shows molecules with a "backbone" (e.g., polymers, proteins) and depicts alpha helices as curled ribbons.	Shows the secondary structure (such as locations of any alpha helices) of a protein.	Used for proteins and other polymers; does not show individual atoms and other important structural features.

Tables of Common Polyatomic Ions

The tables below list common polyatomic ions that you will be using throughout this General-Chemistry laboratory series (Chem 151-152). These ions are separated by charge on the ion into four (4) different tables and listed alphabetically within each table. For each polyatomic ion, the name, chemical formula, two-dimensional drawing, and three-dimensional representation are given.

The three-dimensional structures are drawn as CPK models. CPK structures represent the atoms as spheres, where the radius of the sphere is equal to the van der Waals radius of the atom; these structures give an approximate volume of the polyatomic ion. In these tables, the three-dimensional structures have all been drawn to the same scale; therefore you can compare their relative sizes. In addition, the atoms in the CPK structures have been color-coded to match the two-dimensional drawings for easier comparison. To view the ions interactively, please use Chime. For

[1] It is also called space-filling models. CPK stands for the names of the three scientists who designed and developed this model to represent biological macromolecules in 1960.

viewing and rotating the ions listed in the tables below, please click on the appropriate three-dimensional structure.

Table 1: Cations (+1 Charge)

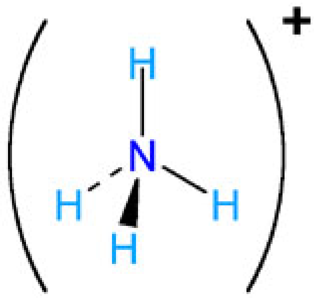
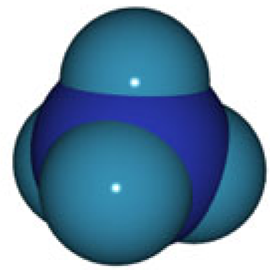
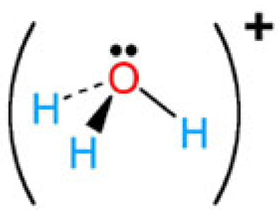
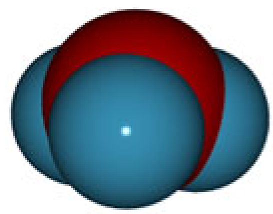
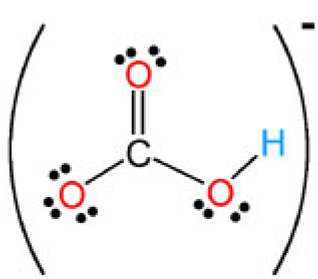
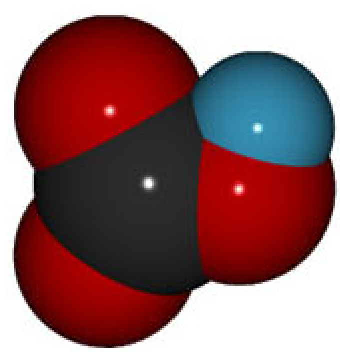
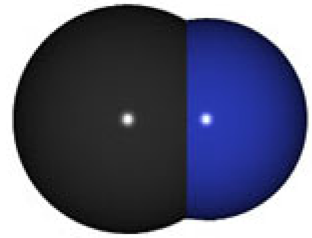
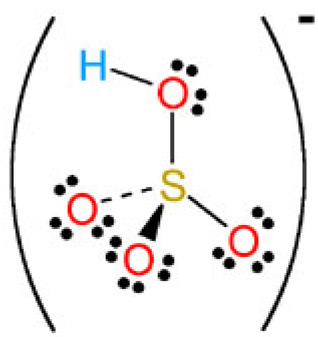
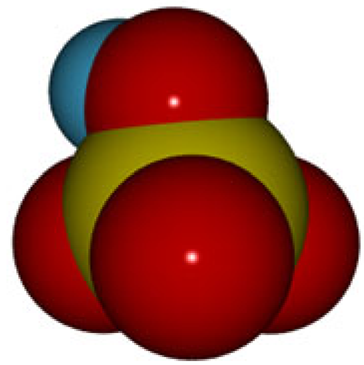
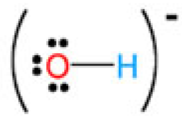
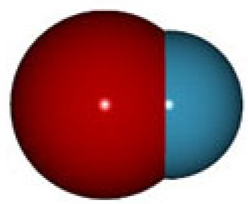
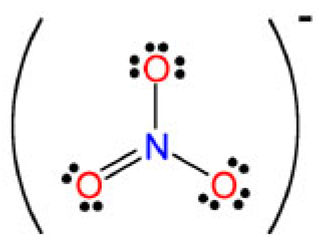
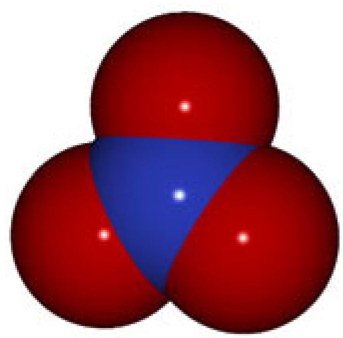
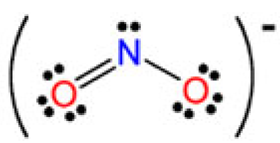
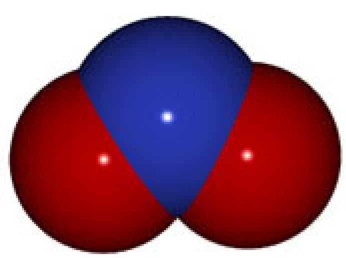
Ion	Two-Dimensional Structure	Three-Dimensional Representation
Ammonium NH_4^+		
Hydronium H_3O^+		

Table 2: Anions (-1 Charge)

Ion	Two-Dimensional Structure	Three-Dimensional Representation
Bicarbonate HCO_3^-		

Cyanide CN^-		
Hydrogen Sulfate HSO_4^-		
Hydroxide OH^-		
Nitrate NO_3^-		
Nitrite NO_2^-		

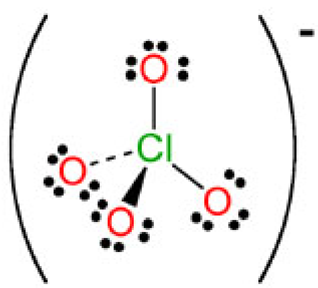
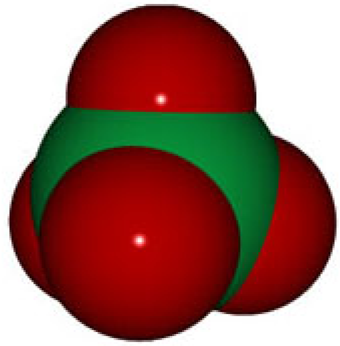
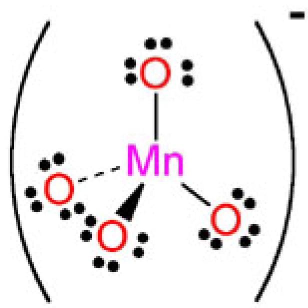
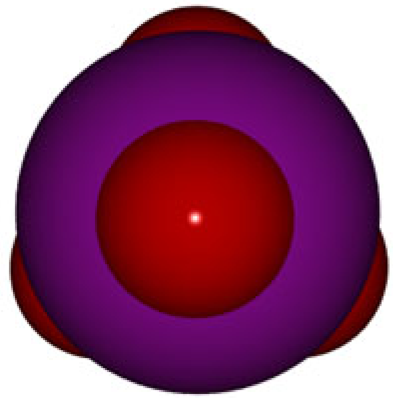
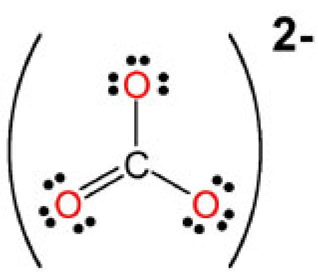
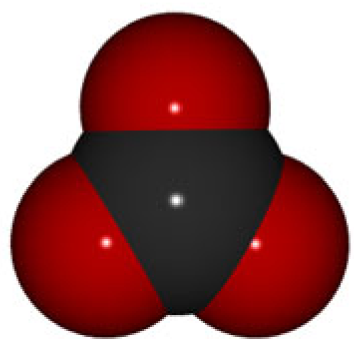
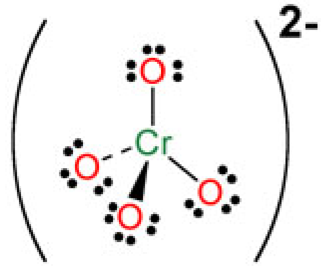
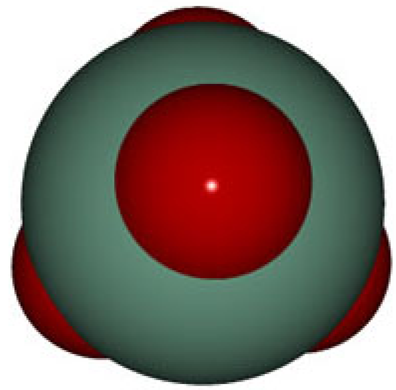
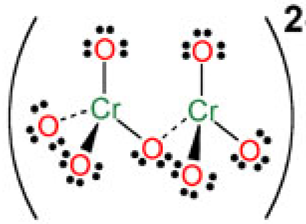
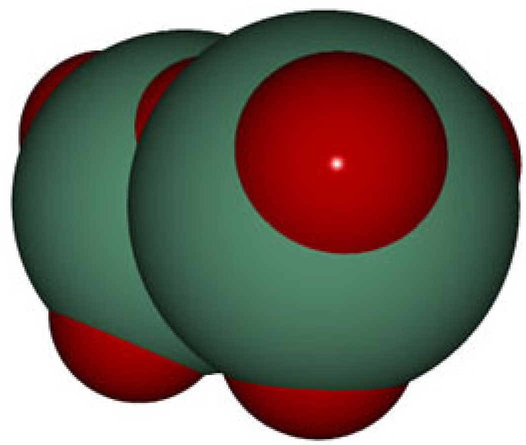
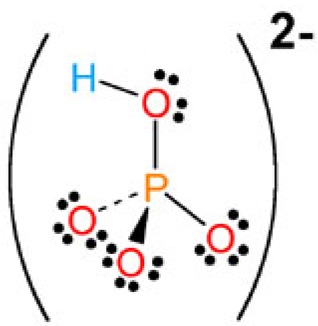
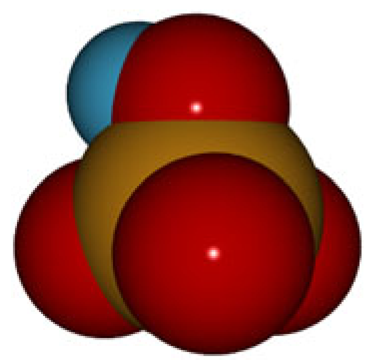
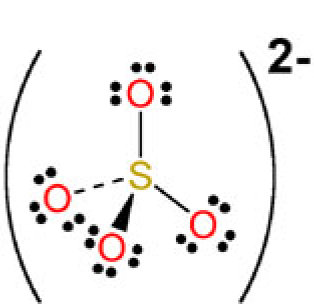
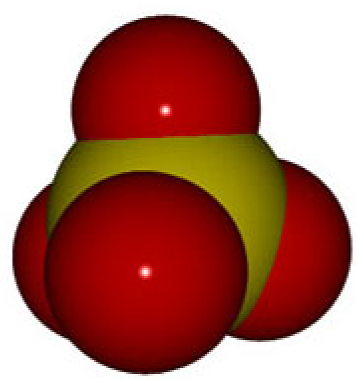
Perchlorate ClO_4^-		
Permanganate MnO_4^-		

Table 3: Anions (-2 Charge)

Ion	Two-Dimensional Structure	Three-Dimensional Representation
Carbonate CO_3^{2-}		

Chromate CrO_4^{2-}		
Dichromate $Cr_2O_7^{2-}$		
Hydrogen Phosphate HPO_4^{2-}		
Sulfate SO_4^{2-}		

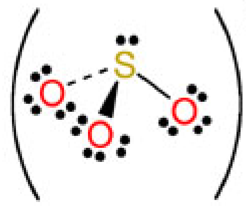
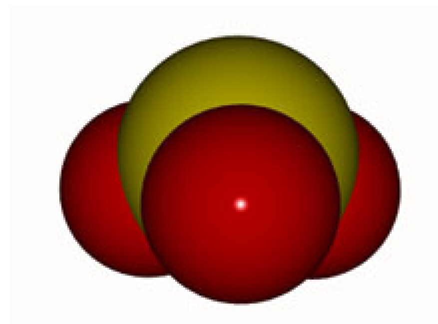
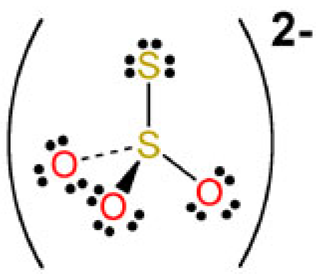
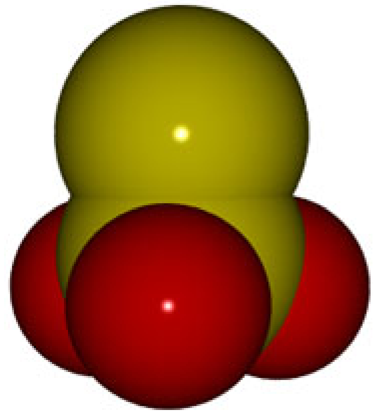
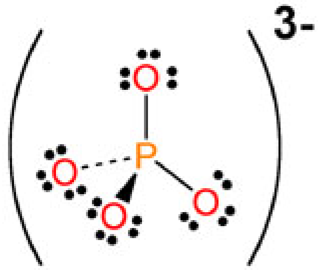
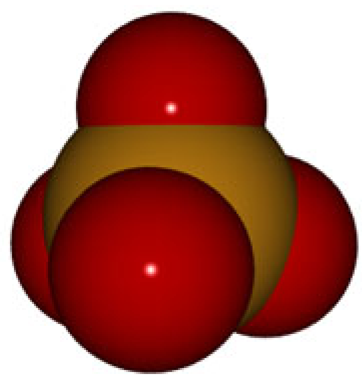
Sulfite SO_3^{2-}		
Thiosulfate $S_2O_3^{2-}$		

Table 4: Anions (-3 Charge)

Ion	Two-Dimensional Structure	Three-Dimensional Representation
Phosphate PO_4^{3-}		

Naming Coordination Compounds

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Please click here for a pdf version of this tutorial.

A **coordination complex** is a substance in which a metal atom or ion accepts electrons from (and thus associates with) a group of neutral molecules or anions called **ligands**. A complex can be an anion, a cation ion, or a neutral molecule. **Coordination compounds** are neutral substances (i.e. uncharged) in which **at least** one ion is present as a complex. You will learn more about coordination compounds in the lab lectures for experiment 5 in this course.

The coordination compounds are named in the following way. (At the end of this tutorial, there are additional examples that demonstrate how coordination compounds are named.)

A. When naming coordination compounds, **always name the cation before the anion.** This rule holds regardless of whether the complex ion is the cation or the anion. (This is just like naming an ionic compound.)

B. In naming the complex ion:

1. **Name the ligands first, in alphabetical order, and then name the metal atom or ion**. **Note:** The **metal atom or ion** is written **before** the **ligands** in the **chemical formula**.
2. The names of some common ligands are listed in Table 1.
   - *Anionic ligands end in "-o."* For anions that end in "-ide"(e.g. chloride, hydroxide), "-ate" (e.g. sulfate, nitrate), and "-ite" (e.g. nirite), change the endings as follows:
     -ide $\rightarrow$ -o; e.g., chloride $\rightarrow$ chloro and hydroxide $\rightarrow$ hydroxo
     -ate $\rightarrow$ -ato; e.g., sulfate $\rightarrow$ sulfato and nitrate $\rightarrow$ nitrato
     -ite $\rightarrow$ -ito; e.g., nitrite $\rightarrow$ nitrito
   - For neutral ligands, the common name of the molecule is used (e.g. $H_2NCH_2CH_2NH_2$ (ethylenediamine)). **Important exceptions**: water is called 'aqua', ammonia is called 'ammine', carbon monoxide is called 'carbonyl', and the N_2 and O_2 molecules are called 'dinitrogen' and 'dioxygen'.

Table 1. Names of Some Common Ligands

Anionic Ligands	Names
Br^-	bromo
F^- fluoro	
O^{2-} oxo	
OH^- hydroxo	
CN^- cyano	
$C_2O_4^{2-}$	oxalato
CO_3^{2-}	carbonato
CH_3COO^- acetato	

Neutral Ligands	Names
NH_3 amm	ine
H_2O aqua	
NO	Nitrosyl
CO	Carbonyl
O_2 dioxygen	
N_2 dinitrogen	
C_5H_5N pyridin	e
$H_2NCH_2CH_2NH_2$	ethylenediamine

3. The Greek prefixes di-, tri-, tetra-, etc. are used to designate the number of each type of ligand in the complex ion. If the ligand already contains a Greek prefix (e.g. ethylene**di**amine) or if it is a polydentate ligand (i.e. it can attach at more than one coordination site), the prefixes bis-, tris-, tetrakis-, and pentakis- are used instead (See examples 3 and 4). The numerical prefixes are listed in Table 2.

Table 2. Numerical Prefixes

Number	Prefix	Number	Prefix	Number	Prefix
1 mono		5 penta	(pentakis)	9 nona	(ennea)
2	di (bis)	6	hexa (hexakis)	10	deca
3 tri	(tris)	7 hepta		11	undeca
4 tetra	(tetrakis)	8 octa		12	dodeca

4. After naming the ligands, name the central metal. If the complex ion is a cation, the metal is named same as the element. For example, Co in a complex cation is called cobalt and Pt is called platinum. (See examples 1-4.) If the complex ion is an anion, the name of the metal ends with the suffix -ate. (See examples 5 and 6.) For example, Co in a complex anion is called cobaltate and Pt is called platinate. For some metals, the Latin names are used in the complex anions (e.g. Fe is called ferrate and not ironate).

Table 3: Name of Metals in Anionic Complexes

Name of Metal	Name in an Anionic Complex
Iron Ferrate	
Copper Cuprate	
Lead Plum	bate
Silver Argentate	
Gold Aurate	
Tin Stannate	

5. Following the name of the metal, the oxidation state of the metal in the complex is given as a Roman numeral in parentheses.

C. To name a neutral complex molecule, follow the rules of naming a complex cation. **Remember:** Name the (possibly complex) cation **BEFORE** the (possibly complex) anion. See examples 7 and 8.

For historic reasons, some coordination compounds are called by their common names. For example, $Fe(CN)_6^{3-}$ and $Fe(CN)_6^{4-}$ are named ferricyanide and ferrocyanide respectively, and $Fe(CO)_5$ is called iron carbonyl.

Examples Give the systematic names for the following coordination compounds:

1. $[Cr(NH_3)_3(H_2O)_3]Cl_3$

Answer: triamminetriaquachromium(III) chloride

Solution:

- ***The complex ion is found inside the parentheses. In this case, the complex ion is a cation.***
- ***The ammine ligands are named first because alphabetically, "ammine" comes before "aqua."***

- ***The compound is electrically neutral and thus has an overall charge of zero. Since there are three chlorides associated with one complex ion and each chloride has a –1 charge, the charge on the complex ion must be +3.***
- ***From the charge on the complex ion and the charge on the ligands, we can calculate the oxidation number of the metal. In this example, all the ligands are neutral molecules. Therefore, the oxidation number of chromium must be the same as the charge of the complex ion, +3.***

2. $[Pt(NH_3)_5Cl]Br_3$

Answer: **pentaamminechloroplatinum(IV) bromide**

Solution:

- ***The complex ion is a cation, and the counter anions are the 3 bromides.***
- ***The charge of the complex ion must be +3 since it is associated with 3 bromides.***
- ***The NH_3 molecules are neutral while the chloride carries a –1 charge.***
- ***Therefore, the oxidation number of platinum must be +4.***

3. $[Pt(H_2NCH_2CH_2NH_2)_2Cl_2]Cl_2$

Answer: **dichlorobis(ethylenediamine)platinum(IV) chloride**

Solution:

- ***Since Ethylenediamine is a bidentate ligand, the prefix bis- is used instead of the prefix di-.***

4. $[Co(H_2NCH_2CH_2NH_2)_3]_2(SO_4)_3$

Answer: **tris(ethylenediamine)cobalt(III) sulfate**

Solution:

- ***The sulfate has a charge of –2 and is the counter anion in this molecule.***
- ***Since it takes 3 sulfates to bond with two complex cations, the charge on each complex cation must be +3.***
- ***Since ethylenediamine is a neutral molecule, the oxidation number of cobalt in the complex ion must be +3.***
- ***Again, remember that you never have to indicate the number of cations and anions in the name of an ionic compound.***

5. $K_4[Fe(CN)_6]$

Answer: **potassium hexacyanoferrate(II)**

Solution:

- ***Potassium is the cation, and the complex ion is the anion.***
- ***Since there are 4 K^+ associated with the complex ion (each K^+ having a +1 charge), the charge on the complex ion must be –4.***
- ***Since each ligand carries –1 charge, the oxidation number of Fe must be +2.***
- ***The common name of this compound is potassium ferrocyanide.***

6. $Na_2[NiCl_4]$

Answer: **sodium tetrachloronickelate(II)**

Solution:

- ***The complex ion is the anion so we have to add the suffix –ate to the name of the metal.***

7. $Pt(NH_3)_2Cl_4$

Answer: **diamminetetrachloroplatinum(IV)**

Solution:

- ***This is a neutral molecule because the charge on Pt^{+4} equals the negative charges on the four chloro ligands.***
- ***If the compound is $[Pt(NH_3)_2Cl_2]Cl_2$, even though the number of ions and atoms in the mo lecule are identical to the example, it should be n amed: diamminedichloroplatinum(IV) chloride because the pla tinum in the latter compound is only four coordinated instead of six coordinated.***

8. $Fe(CO)_5$

Answer: **pentacarbonyliron(0)**

Solution:

- ***Since it is a neutral complex, it is named in the same way as a complex cation. The common name of this compound, iron carbonyl, is used more often.***

9. $(NH_4)_2[Ni(C_2O_4)_2(H_2O)_2]$

Answer: **ammonium diaquabis(oxalato)nickelate(II)**

Solution: ***The oxalate ion is a bidentate ligand.***

10. $[Ag(NH_3)_2][Ag(CN)_2]$

Answer: **diamminesilver(I) dicyanoargentate(I)**

You can have a compo und where both the cation and the anion are complex ions . Notice how the name of the metal differs even though they are the same metal ions.

Can you give the molecular formulas of the following coordination compounds?

1. hexaammineiron(III) nitrate
2. ammonium tetrachlorocuprate(II)
3. sodium monochloropentacyanoferrate(III)
4. potassium hexafluorocobaltate(III)

Can you give the name of the following coordination compounds?

5. $[CoBr(NH_3)_5]SO_4$
6. $[Fe(NH_3)_6][Cr(CN)_6]$
7. $[Co(SO_4)(NH_3)_5]^+$
8. $[Fe(OH)(H_2O)_5]^{2+}$

Answers:

1. $[Fe(NH_3)_6](NO_3)_3$
2. $(NH_4)_2[CuCl_4]$
3. $Na_3[FeCl(CN)_5]$
4. $K_3[CoF_6]$
5. ***pentaamminebromocobalt(III) sulfate***
6. ***hexaammineiron(III) hexacyanochromate (III)***
7. ***pentaamminesulfatocobalt(III) ion***
8. ***pentaaquahydroxoiron(III) ion***