Washington University in St Louis Chemistry 151

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 *For a pdf version click here.*
- 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 cation 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 1.)

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 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: those consisting of a metal combined with a nonmetal (e.g., NaCl, Ag_2S, PbO) and those 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_2S_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 NH_4^+ ions to combine with one SO_4^{2-} ion to give a molecule that carries no charge.

Practice Problems:

(click here to see the answers)

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 nitrogen 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

(click here to see the answers)

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 an 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

(click here to see the answers)

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

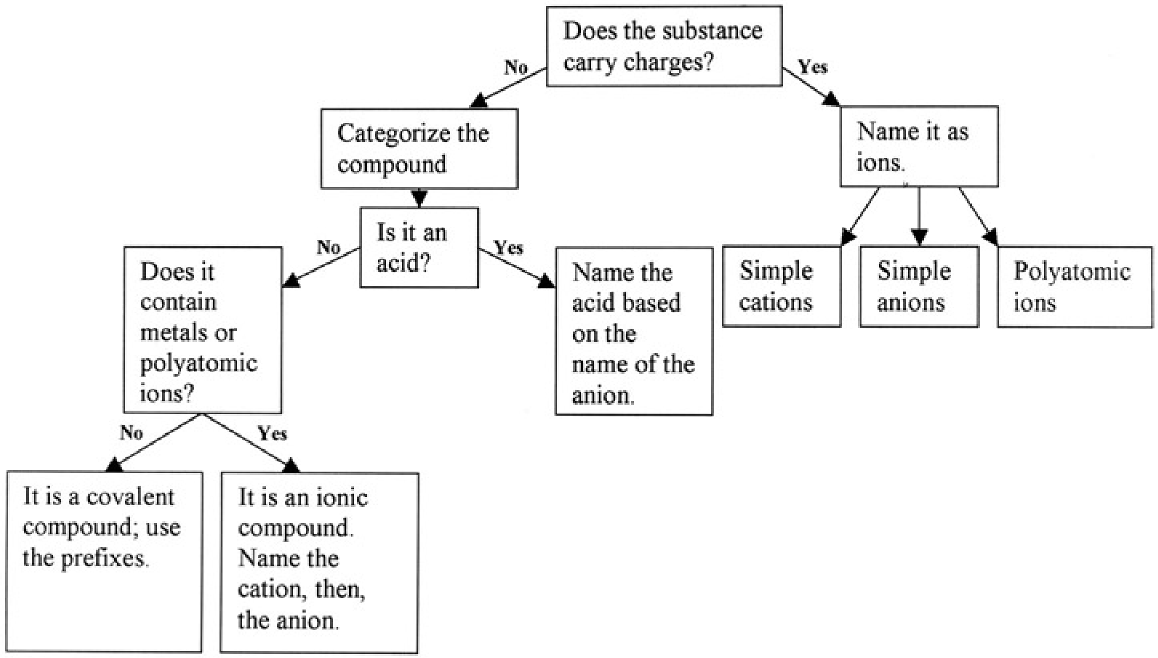
   ammonium hydrogen phosphate

IV. Coordination compounds ----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:



Answer to the Practice Problems:

(click here to go back to the 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	$(NH_4)_2HPO_4$*(the cation is ammonium =* NH_4^+*, the anion is hydrogen phosphate =* HPO_4^{2-}*)*

Acknowledgements:

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

Updated On: 7/8/2011