Ions and Ionic Bond Puzzle

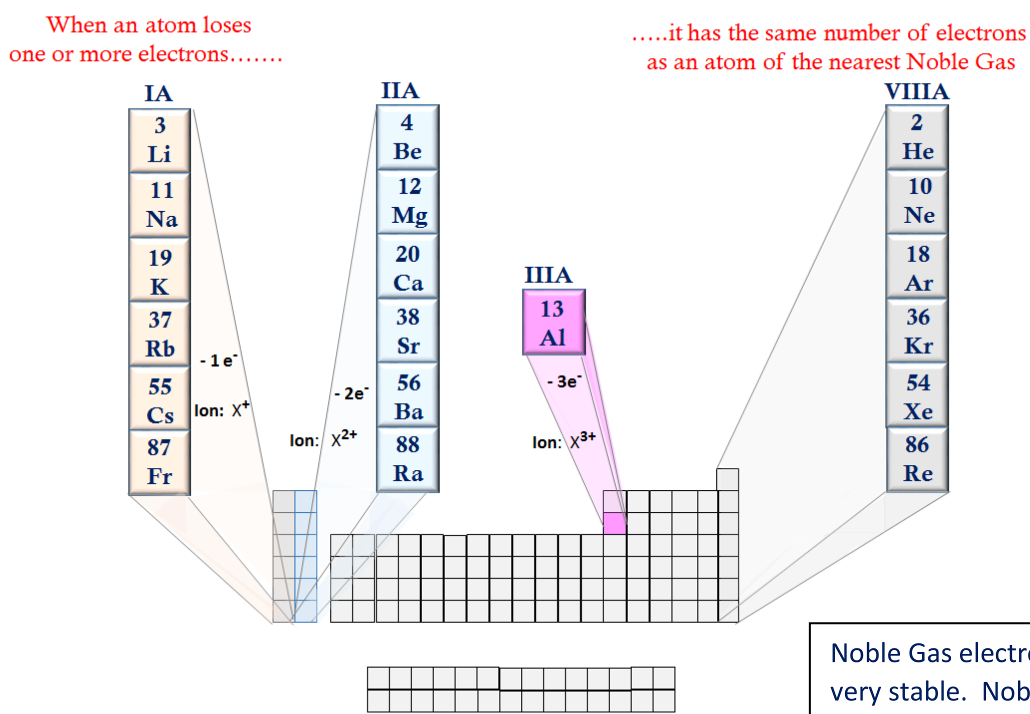
For what does it profit a man if he gains the whole world, and loses or forfeits himself? **Luke 9:25**

Introduction and Pre-Lab

An ***ion*** is an atom, or a group of atoms, having an electrical charge due to either a gain or loss of electrons. A positively-charged ion is called a ***cation;*** and, a negatively-charged ion is called an ***anion***. For the Representative Atoms (Group A atoms), we can predict if any one atom will tend to become a cation or an anion, and how large the charge will be.

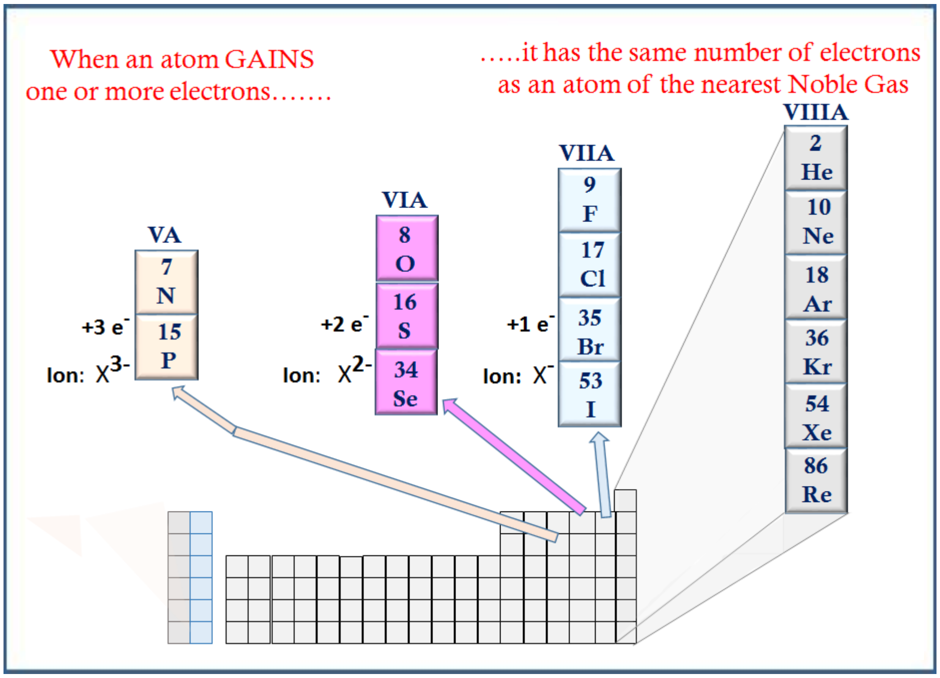
Review the table below. All Groups IA atoms have one valence electron. When they lose this electron they all have a +1 charge. Group IIA atoms have two valence electrons. Losing these electrons, they become ions with a +2 charge. Group IIA atoms, namely Aluminum, has 3 valence electrons. Losing these 3 electrons, aluminum becomes an ion with a +3 charge.

Metallic atoms tend to hold valence electrons relatively loosely, losing them to become cations, and resulting in a full outer valence shell. In doing so, metals reach the electronic configuration of the nearest Noble Gas (Group 8A). Transition Metals (Group B atoms) also lose electrons to form cations. However, the pattern is less predictable, and some may form different charges under different circumstances. For example, iron atoms form both Fe^{2+} and Fe^{3+} ions.



Noble Gas electronic configuration is very stable. Noble Gas atoms do not share, gain or lose electrons.

Likewise, atoms that lose/gain electrons to reach Noble Gas electron configuration, reach a more stable state.



Nonmetals tend to attract electrons more strongly, resulting in a gain of electrons (becoming anions). The farther to the right in the periodic table an element is, the stronger it will attract electrons – a tendency termed ***Electronegativity***. ***Ionization Energy*** is a measure of how much energy is required to remove the valence electrons. Elements to the right in the period table have relatively higher ionization energies, it is very difficult to remove electrons from them. As the figure indicates, a nonmetal will gain electrons in order to have a full outer valence shell just like its nearest Noble Gas neighbor.

Examine the table. Group VA nonmetals have 5 electrons in their outer shell. They tend to gain 3 electrons in order to complete an octet. In doing so, Group VA atoms become ions with a –3 charge. Group VIA atoms, having valence shells of 6, seek to gain 2 electrons, thus becoming ions with –2 charge. Finally, Group VIIA atoms, having valence shells of 7, seek to gain 1 electron, becoming ions with –1 charge.

In this lab we will gain experience in predicting charges and naming monatomic cations and anions. We will be introduced to polyatomic ions and predict the ratios in which they form ionic bonds.

Learning Objectives:

- Predict charges of ions of metals and nonmetals
- Lean about polyatomic ions
- Perform an exercise to predict the ratios in which cations and anions form ionic bonds

Materials Required:

From Chemistry Kit	Student Supplied
Cards (at the end of this protocol)	Periodic Table
Test tubes and holder	Scissors (to cut apart the cards)

PART 1 – Monoatomic Ions

Introduction

A monatomic ion is an ion consisting of one atom that either gained or lost electrons. For example, when sodium (Na) loses its 1 valence electron, it becomes sodium ion, Na^{1+}, (or more typically written Na^{+}). This section will deal with monatomic ions.

Ions having a positive charge are termed ***cations***. Monatomic cations are named with the full name of the metal followed by the word "***ion***". Thus, K^{+} is named ***potassium ion***. If the metallic atom forms ions with multiple charges, then the name is followed by a Roman numeral to indicate the charge. For example, Fe^{2+} is named ***iron(II) ion*** and Fe^{3+} is named ***iron(III) ion***. There is no space between the name and the parentheses. The Roman numerals are not used if the atom only forms an ion with the same charge. For example, cadmium forms almost exclusively ions with +2 charge, so Roman numerals are NOT used in naming the ***cadmium ion***.

Ions having a negative charge are termed ***anions***. Monoatomic anions are named by adding the suffix "***–ide***" to the root of the element name. For example, the oxygen ion O^{2-} is called the ***oxide ion***.

EXPERIMENT:

1. Read the Introduction above and your text, paying attention to:
    - Group number and valence electron umber
    - Varying charges on certain transition metals
    - Ionization energy and electronegativity
    - Electronic Configuration (i.e.: $1s^2 2s^2 2p^5$)

2. Fill out Table 1 and answer the questions in ***Part 1 – Monoatomic Ions***

PART 2 – Polyatomic Ions

Introduction

Polyatomic ions consist of two or more atoms covalently bound together and having an overall charge and reacting as one unit. Above, we discussed how atoms can gain or lose electrons to form ions. Certain molecules may also gain or lose electrons to form polyatomic ions. The atoms of the molecule remain covalently bound. However, since one or more electrons have been gained or lost, there is an overall charge on the molecule. For example, the hydroxide ion consists of oxygen and hydrogen covalently bound together, but with an overall charge of -1. The hydroxide ion is written $\mathbf{OH^{-}}$.

EXPERIMENT:

1. Read the information regarding polyatomic ions

2. Fill out Table 2 and answer the Lab Report questions in ***Part 2 – Polyatomic Ions***

PART 3 – Cation to Anion Ratios and Ionic Formulas

Introduction

Ionic compounds are made up of cations and anions, arrayed in an orderly crystalline manner. The empirical (simplest) formula for an ionic compound depends upon the charge on the cation and the charge on the anion and requires that the positive charges balance the negative charges. For example, when sodium ion and chloride ion combine, they do so in a one-to-one ratio: **Na^+ + Cl^- → NaCl.** The +1 charge on sodium balances the –1 charge on chloride. Notice that the charges are not written in the formula, NaCl, since the charges have been neutralized.

Now consider sodium oxide. Sodium ion has a +1 charge (Na^+) and oxide ion has a –2 charge (O^{2-}). Sodium and oxide may not combine in a one-to-one ratio. Rather, two sodium ions are required to balance the –2 charge on oxide ion. The formula of the ionic compound is Na_2O where the subscript "2" indicates two sodium ions: **$2Na^+$ + O^{-2} → Na_2O.**

Ionic compounds with polyatomic ions behave in the same manner. Remember, the polyatomic ion behaves as one unit with a charge. For example, tin(IV) chromate is made up of a cation and an anion. The cation is tin with +4 charge and written as Sn^{4+}. The anion is chromate with a -2 charge and written as $(Cr_2O_7)^{2-}$. One chromate anion has a -2 charge, but two chromate anions are required to balance the +4 charge on tin. The formula for tin(IV) chromate is $Sn(Cr2O_7)_2$. Note that chromate is placed in parentheses in order to show that there are two chromate ions in this ionic compound. Note also that charges are not written in the formula.

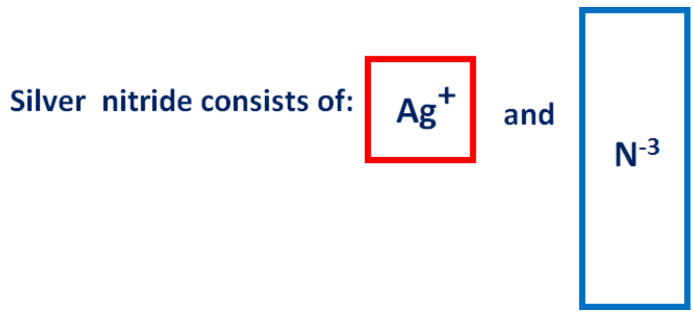
EXPERIMENT:

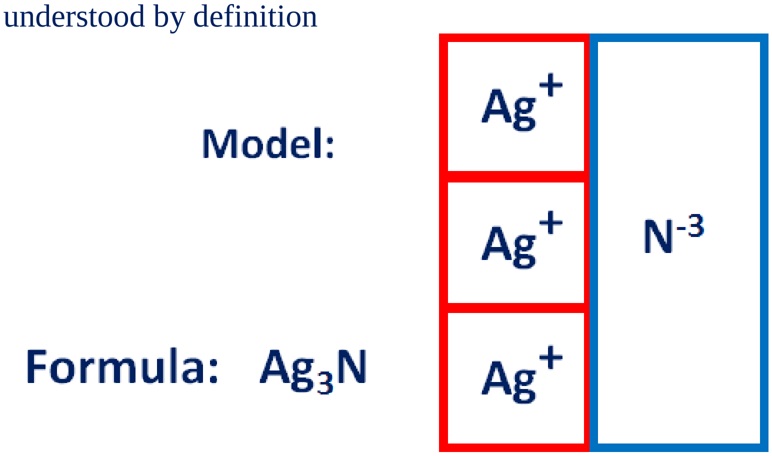
1. Setup
   - Cut out the puzzle pieces from the sheets (at the end of this laboratory protocol)
   - There are multiple types of each ion
     - Keep each type in a separate stack
   - Notice that the charge on the ion is reflected in the height of the puzzle piece
   - Arrange the cations alphabetically in a line on a table
   - Arrange the anions alphabetically in a second line on the table

2. Model
   - Ionic compound names are given in Table 3
   - Locate the ions used in the formula
     - Be sure to use the correct cation if multiple forms are available
   - Model the charge balancing by placing the puzzle pieces together ion
     - Total positive charges must balance total negative charges
     - You may need to use more than one cation and/or anion
   - ***Puzzle is correctly completed when a rectangle has been formed***
     - If charges are balanced, the puzzle should be a rectangle

3. Write
   - Using your models, write the formula for each compound
   - Leave out the charge in the final formula
   - Use subscripts to show the number of cations and the number of anions required to balance charges in your model
   - Use parentheses for polyatomic ions
   - Record in Table 3

4. For example, if given the name: Silver nitride:
   - The <u>cation</u> is silver ion
     - Silver has +1 charge
     - Written as Ag^{+1}
   - The <u>anion</u> is the nitride ion
     - Nitride has -3 charge
     - Written as N^{-3}
   - The magnitude of the <u>charges</u> is symbolized by the height of the puzzle pieces
   - In making the <u>model</u>:
     - It is clear that three silver ions are needed to balance the charge on nitride
     - Only a ratio of 3-to-1 will result in a rectangle
     - Either more or less silver ions would not be a rectangle
   - Write the <u>formula</u>
     - Finally, we can write the formula for silver nitride
     - **Formula: Ag_3N**
     - The subscript "3" indicates we used three puzzle pieces (or 3 silver cations) to balance charges
     - **Note**: There is not a subscript of "1" used for the nitride ion since the "1" is understood by definition





5. Complete Table 3 and the associated questions

Lab Report for: ______________________________

PART 1 – Monoatomic Ions

1. For each of the following, identify which Group (e.g., alkali metal) the element belongs to; decide whether it will form an anion or a cation, and what charge(s) it is likely to have.

TABLE 1 – MONOATOMIC IONS

Element Symbol	Group Name	Anion (a) or Cation (c)?	Ion Name	Charge
I				
Ca				
Fr				
Au				
Cs				
N				
Br				
Li				
S				
Np				------

2. Does a cation have a positive or a negative charge? __________________

3. Scientists have discovered a new element with Atomic Number = 120.
   - Would the element be more likely to form a cation or an anion? _____________
   - What charge would the ion form of this new element have? (Assume the trends you have learned continue.) ________________________
   - Explain your answers.

4. Chlorine tends to form an ion by <u>gaining</u> an electron.
   - Does chlorine have high or low ionization energy? ___________

5. Which group of elements has such high ionization energy that none in the group tend to form ions at all? ____

6. Magnesium (Mg) forms an ion by losing two electrons.
   - Mg^{2+} has the same electron configuration as what element? ______________
   - Write the electron configuration for Mg^{2+}. _____________________________

PART 2 – Polyatomic Ions

1. There is only one common polyatomic cation. Give its name AND formula. ____________

2. In order to review formulas, names and charges of polyatomic ions, fill in the empty boxes

TABLE 2 – POLYATOMIC IONS

FORMULA	NAME	CHARGE
	Acetate	
NH_4^+		1^+
	Carbonate	
ClO_3^-		1^-
	Chlorite	
CrO_4^{2-}		2^-
	Cyanide	
$Cr_2O_7^{2-}$		2^-
	Dihydrogen phosphate	
HCO_3^-		1^-
	Hydrogen phosphate	
HSO_4^-		1^-
	Hydrogen sulfite	
OH^-		1^-
	Hypochlorite	
NO_3^-		1^-
	Nitrite	
$C_2O_4^{2-}$		2^-
	Perchlorate	
MnO_4^-		1^-
	Phosphate	
PO_3^{3-}		3^-
	Silicate	
SO_4^{2-}		2^-
	Sulfite	

PART 3 – Cation to Anion Ratios and Ionic Formulas

1. After completing the puzzle indicated in Column 1, fill out the cation, anion and the ionic formula. The first is done for you as an example.

TABLE 3 – Ionic Formulas

Column 1 Name	Cation (Symbol & Charge)	Anion (Symbol & Charge)	Ionic Formula
Silver nitride	Ag^{+}	N^{3-}	Ag_3N
Sodium hydride	Ag^{+}		
Sodium hydroxide		OH^{-}	
Magnesium chloride			
Cobalt(II) nitride		N^{3-}	
Ammonium phosphate			
Silver acetate			
Copper(II) oxide		O^{2-}	
Copper(I) oxide		O^{2-}	
Iron(II) nitrate			
Iron(III) carbonate			
Aluminum sulfate			

2. Diagram your model for Cobalt(II) nitride.

Cations:

<table>
<tr><td>Ag^{+}</td><td>Cu^{+}</td><td rowspan="2">Mg^{2+}</td><td rowspan="2">Co^{2+}</td><td rowspan="2">Fe^{2+}</td></tr>
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</table>

Cu^{2+}	Cu^{2+}	Cu^{2+}	Cu^{2+}	Cu^{2+}
Fe^{3+}	Fe^{3+}	Fe^{3+}	Fe^{3+}	Fe^{3+}
Al^{3+}	Al^{3+}	Al^{3+}	Al^{3+}	Al^{3+}

Anions:

<table>
<tr><td>H^-</td><td>OH^-</td><td rowspan="2">O^{2-}</td><td rowspan="2">CO_3^{2-}</td><td rowspan="2">SO_4^{2-}</td></tr>
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</table>

Cl^-	$C_2H_3O_2^-$			
Cu^{2+}	Cu^{2+}	Cu^{2+}	Cu^{2+}	Cu^{2+}
N^{3-}	N^{3-}	N^{3-}	N^{3-}	N^{3-}
$PO4^{3-}$	$PO4^{3-}$	$PO4^{3-}$	$PO4^{3-}$	$PO4^{3-}$
NO_3^-	NO_3^-	NO_3^-	NO_3^-	NO_3^-