Classification of Ionic and Molecular Compounds and their Nomenclature

Prelab

Read the entire laboratory write up. Write an objective and answer the following questions in your laboratory notebook before coming to the lab. Read the entire laboratory write up before answering these questions.

Prelab questions:

1. Completely and uniquely define the following words
   (a) Element
   (b) Compound
   (c) Ionic compound
   (d) Molecular compound
   (e) Monoatomic ion
   (f) Polyatomic ion
   (g) Transition metal

Activity 1

Objective

- Based on the elements present in a chemical formula, classify the compound as ionic or molecular.

Getting Started

Review the definitions for an element and a compound. An element is a pure substance that cannot be broken down to a different substance by a chemical reaction. A compound is two or more elements chemically bonded in a fixed ratio. A compound has different properties than the elements from which it is composed.

A model is a plan or representation of a system. A model can be viewed as an example of a system. In the following activities you will look for trends and develop rules for classifying and naming compounds by examining models.

The Model

Cu is the elemental form of copper.
C is the elemental form of carbon
O_2 is the elemental form of oxygen
CuO is a compound formed from the elements copper and oxygen.
CO_2 is a compound formed from the elements carbon and oxygen.

Reviewing the Model

1. What does the subscript 2 indicate in O_2?
2. What is implied when there is no subscript?
3. Classify C, Cu and O as metals or nonmetals.

Exploring the Model

4. Evaluate the statement, "The formulas for elements never contain a subscript." Is this statement true?
5. From the two examples provided in "The Model", would you expect the formula S_8 to represent a compound or an element?
6. Using examples from "The Model", explain how you classified S_8.

Exercising Your Knowledge

7. Classify each formula below as an element or a compound.

   Fe_____

   $CaCl_2$_____

   KOH_____

   Cl_2_____

   $NaCl$_____

   SiO_2_____

   PF_5_____

   P_4_____

   SO_2_____

Summarizing Your Thoughts

8. What clues given in a chemical formula allow you to differentiate between an element and a compound?

Activity 2

Getting Started

There are two major classes of compounds typically encountered as part of an introductory course: ionic and molecular (also called covalent) compounds. We will talk about the chemical reactions that form these two types of compounds later. However, you must be able to quickly classify a compound as either ionic or molecular in order to know which set of rules you should use to name a compound. There are clues in the chemical formula. It is your job to use the Model below to find these clues.

The Model

Table 1

Ionic	Molecular
$PbCl_2$	CCl_4
K_2O	P_2O_5
Fe_2S_3	N_2O_4
CuBr	NI_3

Reviewing the Model

1. The compound $PbCl_2$ is considered to be a (an) _____ compound.
2. The compound that contains nitrogen and oxygen is a (an) _____ compound.
3. List all the elements included in the model.

Exploring the Model

4. Does the classification seem to be made based on how many atoms of each element are represented in the formula?

5. Where on the periodic table is each of the elements in the model located (left or right side)?

6. Classify each element as either a metal or a nonmetal.

7. Compare the types of elements found (metals or nonmetals) for the two classes of compounds. Do you see any trend in the type of elements present and the classification? Describe the trend(s) you see.

Exercising Your Knowledge

8. Classify each of the following as either ionic or molecular.

   $CsBr$_____

   SF_6_____

   CoI_2_____

   NO_2_____

   SO_2_____

   BaS_____

   CaF_2_____

   $CrCl_3$_____

   CO_2_____

   CO_____

Summarizing Your Thoughts

9. Write a simple rule that will allow you to classify compounds as ionic or molecular on the basis of what you have learned from the Model.

Activity 3

Objective

- Identify some simple rules about nomenclature (naming) for ionic compounds.

The Model

Examine the table below, and answer the following questions.

Table 2

Cation	Anion	Chemical Formula	Compound Name
Na^+	Cl^-	NaCl	Sodium chloride
Ca^{2+}	O^{2-}	CaO	Calcium oxide
Zn^{2+}	Cl^-	$ZnCl_2$	Zinc chloride
Li^+	S^{2-}	Li_2S	Lithium sulfide
K^+	N^{3-}	K_3N	Potassium nitride

Reviewing the Model

1. Are ALL cations positive ions or negative ions? _____
2. Are ALL anions positive ions or negative ions? _____
3. What is the name of the compound formed by the combination of Li^+ ions and S^{2-} ions?

Exploring the Model

4. When the name of an ionic compound is given, which ion appears first?

5. Compare the first word of the compound names to the name of the element from the periodic table. How does the name of the cation correspond to the name of the element?

6. Compare the second word of the compound name to the name of the element from the periodic table. How does the name of the anion correspond to the name of the element?

7. From what part of the periodic table do the cations in the Model come (metals or nonmetals)?

8. From what part of the periodic table do the anions in the Model come?

Exercising Your Knowledge

9. For each of the following, predict whether the ion will likely be a cation or an anion.
   a. Magnesium ion
   b. Selenide ion
   c. Bromide ion
   d. Cesium ion

10. For each ionic compound, identify the cation and the anion.
    a. Sodium fluoride
    b. Strontium sulfide
    c. Lithium iodide
    d. Barium chloride

11. In what way did the name provide clues about the classification of each element as a cation or anion?

12. Where on the periodic table would you expect to find elements that ionize to form cations?

13. Where on the periodic table would you expect to find elements that ionize to form anions?

Summarizing Your Thoughts

14. Consider the clues you identified, and write a general rule for how you change the name of elements to cations when naming ionic compounds.

15. Consider the clues you identified, and write a general rule for how you change the name of elements to anions when naming ionic compounds.

16. List at *least* three necessary steps to give the correct name for an ionic compound. (If needed, use a chemical formula of a compound from the table above as an example in listing the naming steps).

Activity 4

Predicting the correct chemical formula for Ionic Compounds Formed from Simple Anions

Objective

- To learn how to predict the correct number of cations or anions in a simple salt.

The Model

Examine the table below, and answer the following questions

Table 3

Cation	Anion	Chemical Formula	Compound Name
Na^+	Cl^-	NaCl	Sodium chloride
Ca^{2+}	Cl^-	$CaCl_2$	Calcium chloride
Na^+	S^{2-}	Na_2S	Sodium sulfide
K^+	N^{3-}	K_3N	Potassium nitride

Reviewing the Model

1. What is the charge on the calcium ion? _____
2. What is the charge on the nitride ion? _____
3. What id the charge on the chloride ion? _____
4. What is the charge on the ionic compound, sodium chloride? _____
5. What is the charge on the ionic compound, sodium sulfide? _____
6. How many potassium ions are present in K_3N? _____
7. What does the "2" stand for in the formula for $CaCl_2$? _____

Exploring the Model

8. Sodium chloride is NaCl, and calcium chloride is $CaCl_2$. Why are there more chloride ions in the calcium containing compound?

9. Sodium chloride is NaCl, and sodium sulfide is Na_2S. Why are there more sodium ions in the sulfide compound?

Exercising Your Knowledge

10. How many chloride ions would combine with an Al^{3+} ion to form aluminum chloride?

11. What charge does the barium ion possess in the compound $BaCl_2$?

Summarizing Your Thoughts

12. Explain how you determined the number of chloride ions needed in aluminum chloride.

13. From the table and the answers above, what do you know about the overall charge on ALL ionic compounds?

14. List at *least* three necessary steps to obtain the correct formula of any simple ionic compound.

Activity 5

Objective

- Understand how to write the chemical formula of ionic compounds containing transition metals with varying charges

Getting Started

When a Group 1A metal forms a cation, it will always form a +1 cation. When a Group 2A metal forms a cation, it will always form a +2 cation: However, as we progress into the transition metals we find that these metals can form cations with different charges under different circumstances. Use the Model below to develop some rules that describe how to communicate the charge of the cation for transition metals.

The Model

Examine the table below, and answer the following questions.

Table 4

Chemical Formula	Compound Name
FeI_2	Iron(II) iodide
FeI_3	Iron(III) iodide
PbS	Lead(II) sulfide
PbS_2	Lead(IV) sulfide
Cu_3N	Copper(I) nitride
Cu_3N_2	Copper(II) nitride

Reviewing the Model

1. What is the expected charge on the Iodide ion?

2. What is the expected charge on the sulfide ion?

3. What is the expected charge on the nitride ion?

4. Represent the Roman numeral II as an Arabic numeral (or as a number in the system you are familiar with).

5. Represent the Roman numeral III as an Arabic numeral.

6. Represent the Roman numeral IV as an Arabic numeral.

Exploring the Model

7. Use your rules developed in Activity 4 to determine the charge on the iron ion in these compounds:

   Charge on iron in $FeBr_2$:
   Charge on iron in $FeBr_3$:

8. How is the Roman numeral in the compound name related to the charge on the iron atoms?

9. Does this hold true for all the compounds in the table above?

10. What types of metals require the use of a Roman numeral in the name of their ionic compounds?

11. Where are these metals located on the periodic table?

Exercising Your Knowledge

12. Why do the compounds in this activity require Roman numerals in the name while compounds such as calcium chloride do not?

13. If only the chemical formulas were given for the compounds in the above examples, how could you determine the value of charge on the cation?

14. Complete the table that follows with the proper ions, chemical formulas, and compound names. The first row has been completed as an example.

Table 5

Cation	Anion	Chemical Formula	Compound Name
Na^{+}	Cl^{-}	NaCl	Sodium Chloride
Ba^{2+}	F^{-}	BaF_2	
Mn^{2+}	O^{2-}		Manganese(II) oxide
Sr^{2+}	N^{3-}		
			Cobalt(III) chloride
		CrO	
Cu^{+}	S^{2-}		
		Mg_3P_2	
		SnS_2	

Summarizing Your Thoughts

15. How will you know when to use Roman numerals when writing the name of an ionic compound?

16. Look at your answer from Activity 4 that lists the steps necessary to give the correct name of an ionic compound from its chemical formula. How do the steps differ when ions with varying charges are involved?

17. Look at your answer from Activity 5 that lists the steps necessary to give the correct chemical formula of an ionic compound given its name. How do the steps differ when ions with varying charges are involved?

Activity 6

Objective

- Recognize the names of polyatomic ions, and understand how to write the chemical formulas of ionic compounds containing polyatomic ions.

Getting Started

Thus far we have considered only simple, monoatomic cations and anions. There is another class of ions that are often call polyatomic ions. Polyatomic ions are a group of different atoms and the entire group of atoms carries the charge. The most common polyatomic ions contain oxygen. Their names may not seem to make sense now, but there is a system to this madness. It is your task to study the Model and determine what the nomenclature rules are.

The Model

Table 6

Ion	Name	Ion	Name
N^{3-}	Nitride	S^{2-}	Sulfide
NO_2^-	Nitrite	SO_3^{2-}	Sulfite
NO_3^-	Nitrate	SO_4^{2-}	Sulfate

Reviewing the Model

1. What element is associated with the prefix “nitr-”?

2. What element is associated with the prefix “sulf-”?

3. What is the ending (suffix) when there are no oxygen atoms in the formula?

4. What suffixes are used when oxygen is included in the formula?

Exploring the Model

5. Does the suffix of each name depend on the charge of the ion?

6. Does the suffix tell you how many oxygen atoms there are?

7. Compare the nitrate to the nitrite. Which ion has more oxygen atoms?

8. Compare sulfate to sulfite. Which ion has more oxygen atoms?

Exercising Your Knowledge

9. Consider the two oxo- ions of chlorine, ClO_2^- and ClO_3^-. Which ion would have the –ate ending?
   a. Write the names of these two oxo- ions of chlorine.

10. Consider the two oxo- ions of phosphorus, PO_3^{3-} and PO_4^{3-}. Which ion would have an –ate ending?

    a. Write the names of these two oxo- ions of phosphorus.

11. In the movie *Star Wars Episode V: The Empire Strikes Back*, the character Han solo is frozen in the fictional material, carbonite. If the carbonite ion existed, what would be its likely chemical formula?

12. Why would it be unlikely for a solid material to be made entirely of pure carbonite ions?

Summarizing Your Thoughts

13. The last three letters of a name can tell a lot about a particle! For each of the name endings below; give a general description of what type of ion or particle would be expected to have that ending (such as cation, monoatomic anion, polyatomic anion, metal element, and/or nonmetal element).
    a. –ide _____
    b. –ium _____
    c. –ate _____
    d. –ine _____
    e. –ite _____

Activity 7

Getting Started

Now that we have introduced polyatomic ions, we have to consider how this new twist affects the name of a compound and how we write the chemical formula.

The Model

Table 7

Chemical Formula	Compound Name
$MgSO_4$	Magnesium sulfate
$MgSO_3$	Magnesium sulfite
Li_3PO_4	Lithium phosphate
$CaCO_3$	Calcium carbonate
NH_4Cl	Ammonium chloride
$Sr(NO_2)_2$	Strontium nitrite
$Ba_3(PO_4)_2$	Barium phosphate
$Fe(NO_3)_3$	Iron(III) nitrate
$Al(OH)_3$	Aluminum hydroxide

Reviewing the Model

1. Write the name and symbol for all the monoatomic ions in the Model.

2. Write the name and formula (including the charge) for all the polyatomic ions in the Model.

3. The ammonium cation is the only polyatomic cation in the Model. What are the formula and the charge of the ammonium cation?

4. How many nitrite ions are present in the strontium nitrite? _____
5. What new symbol is used in these chemical formulas?

Exploring the Model

6. Do all polyatomic ions require the use of parentheses?

7. When are parentheses used?

8. Have the nomenclature rules you established earlier in this chapter changed? If so, how?

9. How many nitrogen atoms are in strontium nitrite? _____

10. Describe the process you used to determine the number of nitrogen atoms in strontium nitrite.

11. How many oxygen atoms are in strontium nitrite? _____

12. In what way does determining the number of oxygen atoms differ from the process you just described for nitrogen?

13. If the parentheses were omitted and aluminum hydroxide was written as $AlOH_3$, how would that change the number of atoms of each element present in the compound?

Exercising Your Knowledge

14. How many of each element is present in aluminum hydroxide?
    a. Aluminum: _____
    b. Oxygen: _____
    c. Hydrogen: _____

15. Complete the table below with the proper ions, chemical formulas, and compound names. The first row is completed as an example.

Table 8

Cation	Anion	Chemical Formula	Compound Name
Na^+	Cl^-	NaCl	Sodium chloride
		LiCN	Lithium cyanide
Ca^{2+}	OH^-		
Fe^{2+}	NO_3^-		
			Barium Phosphate
Cr^{2+}	PO_4^{3-}		
K^+	SO_3^{2-}		
			Ammonium Carbonate
		Au_3PO_4	
			Copper(II) Cyanide

Summarizing Your Thoughts

16. Write a rule that can be used to determine whether or not parentheses are needed when writing a chemical formula.

17. Make a list of information you must know in order to write the correct formula for an ionic compound (this list may require reviewing all the activities you have completed so far in this lab).

Activity 8

Objectives

- Given a molecular compound's name, be able to give the proper chemical formula for the compound
- Given a molecular compound's chemical formula, be able to give the proper name for the compound

Getting Started

We will be using gases and other compounds as illustrations of naming molecular compounds. Molecular compounds are defined as groups of atoms that share electrons in chemical bonds. There are an infinite number of molecular compounds. Almost all of the compounds you will study in Organic Chemistry will be molecular compounds. Here, we will be focusing on naming some of the smaller inorganic molecular compounds.

Use the Model to see if you can figure out how the rules for naming inorganic.

The Model

Table 9

Compound Name	Compound Molecular Formula
Phosphorus hexafluoride	PF_6
Tetracarbon decahydride	C_4H_{10}
Boron trichloride	BF_3
Dinitrogen oxide	N_2O
Carbon monoxide	CO
Dinitrogen tetroxide	N_2O_4

Reviewing the Model

1. Where on the periodic table do you find all the elements used in the Model?

2. What suffix is used for all the compounds? _____
3. Is the name of the first element in each formula changed as it goes from an individual element to a compound? _____
4. How is the name of the second element in each name changed as it goes from an individual element to a compound?

5. How many atoms of nitrogen are present in dinitrogen tetroxide? _____

6. How many atoms of fluorine are present in phosphorus hexafluoride? _____

7. Use the Model to fill the following table with prefixes used to designate the number of each type of atom in a binary compound:

Table 10

Prefix	Number of atoms of elements
	One
	Two
	Three
	Four
	Five
	Six
Hepta-	Seven
	Eight
	Nine
	Ten

Exploring the Model

8. A dentist calls you up and needs to order more laughing gas for his dental clinic. You check in a chemistry reference and find that the chemical name for the laughing gas is dinitrogen monoxide. You may order N_2O, NO, or NO_2. One is the correct compound and the other two are toxic gases. Which should be ordered to keep the patients happy and alive?

Exercising Your Knowledge
From the information given above, complete the following table.

Table 11

Compound Name	Compound Molecular Formula
Sulfur dibromide	
	PCl_3
Silicon dioxide	
	H_2S
Carbon tetrachloride	
	SiF_2
	P_4O_{10}
Carbon dioxide	

Summarizing Your Thoughts

9. In the biological process called respiration, we inhale oxygen and exhale carbon dioxide. When fossil fuels are burned, a toxic gas that may be produced is carbon monoxide. Explain why you wouldn't use the name "carbon oxide" for these molecules.

10. In complete sentences state the rules for naming a molecular compound, given the compound's molecular formula.

11. Compare your rules for naming molecular compounds with the rules you established for writing the names of ionic compounds. Make sure your rules clearly help you decide when you use the prefixes indicating the number of atoms and when you use Roman numerals.