Putting Ions in Their Hands

Covalent, Ionic and Metallic Bonding

Introduction

The first time seeing formulas and names of ionic compounds can be confusing. However, upon further investigation, there are actually simplistic formulated steps to do so. Discover a systematic method of writing formulas for ionic compounds without the need to experimentally determine each formula using cation and anion cards.

Concepts

- Ionic compounds
- Formula writing
- Cations and anions

Background

The *chemical formula* of a compound indicates the kinds of atoms and the relative number of each atom that is combined together to form the compound. *Subscripts* are the numbers written after the chemical element symbols and are used to indicate the number of atoms of each element in the compound. Water, the most abundant chemical on Earth, has the chemical formula H_2O and has a whole-number hydrogen:oxygen atom ratio of 2 to 1.

Some compounds such as sodium chloride, which is common table salt, are composed of *ions*. Ions are atoms or groups of atoms that have a net positive or negative charge. *Cations* are atoms or groups of atoms with a net positive charge, such as Cu^{2+} or NH_4^+, while anions are atoms or groups of atoms with a net negative charge, such as O_2^- or NO_3^-. Atoms of metallic elements tend to form cations while atoms of nonmetallic elements tend to form anions. Ions join together because of an oppositely-charged or electrostatic attraction between a positive cation and a negative anion resulting in an *ionic bond*. Compounds held together by ionic bonds are *ionic compounds*.

Ionic compounds are generally composed of an extended network of positively-charged metal ions and negatively-charged nonmetal ions. Although composed of ions, ionic compounds are electrically neutral, i.e., the total positive charge is equal to the total negative charge. The chemical formula indicates the smallest whole-number ratio of each element in the network of ions and is called a *formula unit*. For example, magnesium chloride has the chemical formula $MgCl_2$. The magnesium cation (Mg^{2+}) and chloride anions (Cl^-) combine in a 1:2 ratio to form $MgCl_2$. The overall charge on the resulting ionic compound is zero. Thus the final compound is composed of two Cl^- ions for each Mg^{2+} ion.

Some ions consist of a group of covalently bonded atoms that tend to stay together as if they were a single ion. Such ions are called *polyatomic ions*. An example is the nitrate ion, NO_3^-. This polyatomic anion contains one nitrogen atom covalently bonded to three oxygen atoms and has an overall charge of –1. Calcium cations, Ca^{2+}, in the presence of nitrate anions, NO_3^-, will combine in a ratio of two nitrate ions for every calcium ion in order to balance the positive and negative charges and achieve electrical neutrality. Thus, the formula for calcium nitrate is written as $Ca(NO_3)_2$, showing that for every calcium ion there are two nitrate ions. Notice that the polyatomic ion is put in parentheses as a unit with the subscript on the outside of the parentheses.

Writing formulas for ionic compounds may be simply determined by following the steps below:

1. The cation is always written first; the anion is written second.
2. The overall charge for an ionic compound is always zero. The charges of the individual ions are never included in the compound's formula.
3. Subscripts are used to indicate the number of atoms of each element in the compound.
4. Parentheses are used around polyatomic ions to show that the subscript pertains to the polyatomic ion as a whole.
5. Assumed subscripts of one are omitted when writing chemical formulas.

Materials

Data Table	Scissors
Envelope	Sheet of anions
Ion Formula Chart	Sheet of cations

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Safety Precautions

This classroom activity is considered nonhazardous. Follow all classroom safety guidelines.

Preparation

Copy the appropriate number of Data Tables, Ion Formula Charts, and Model of Cation–Anion Sheets for each lab group.

Procedure

1. Working in teams or individually, cut all of the positive ion cards from the cation sheet and all of the negative ion cards from the anion sheet. Separate the cations from the anions.
2. Observe carefully the ion cards that have been cut. What do you notice about the height of the cards? What is the relationship between the height and the ion charge?
3. Locate the data table and the Ion Formula Chart.
4. From the cation and anion cards, locate ion cards for the first two combining ions listed in the first column of the data table. The first two, for example, are the aluminum cation and chloride anion. Copy the ionic formula for each ion into the first column of the data table. Use the Ion Formula Chart to look up the ion formulas.
5. Put the cards for the two combining substances together on a flat surface adding additional cards of the same ion until the heights of the cation and anion column are equal. For example, every aluminum cation needs three chloride anions (see Figure 1).

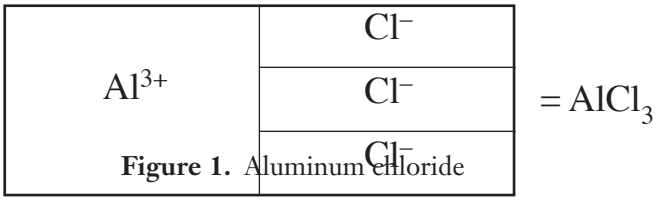

Figure 1. Aluminum chloride

6. Count the number of each ion necessary for the heights to be equal (i.e., for the compound to form). For example, one aluminum cation combines with three chloride anions. Record the number of each ion used in Columns 2 and 3 of the data table. Notice that the numbers recorded in Columns 2 and 3 are the subscripts in the chemical formula of the compound.
7. Determine the total positive charge of the cation card(s) and the total negative charge of the anion card(s) used in forming the compound. These two values will be equal yet opposite in value. For example, the total positive charge is +3 (from one aluminum with a +3 charge) and the total negative charge is –3 (from three chlorides, each with a –1 charge). Record the ionic charges in Columns 4 and 5 of the data table.
8. Write the formula for the ionic compound, using subscripts to indicate the number of each kind of ion used (from Columns 2 and 3). Follow the rules for writing ionic formulas listed in the background material. In our example, the formula is $AlCl_3$. Record the chemical formula for the ionic compound in Column 6 of the data table.
9. Write the name of the ionic compound following the rules for naming ionic compounds discussed in the background information. In our example, the name of the compound is aluminum chloride. Record the name for the ionic compound in the last column of the data table.
10. Repeat steps 2–7 for each set of combining ions in the data table.
11. After writing formulas for all 16 sets of combining ions listed in the data table, complete rows 17–20 of the data table by randomly choosing four more sets of combining ions (that have not already been combined). Follow the procedure in steps 2–7 to complete each column of the data table.
12. Gather the ion cards. Place them in an envelope and return the ion cards to the instructor.

Disposal

The Cards used in this activity may be saved and stored for future use.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Putting Ions in Their Hands* activity, presented by Peg Convery, is available in *Covalent, Ionic and Metallic Bonding*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Putting Ions in Their Hands* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Ionic Formula Writing Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4570	Ionic Formula Writing Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Data Table

Name: _____

Combining Ions	Number of cations	Number of anions	Total + charge	Total – charge	Formula	Name of compound
Aluminum & Chloride						
Sodium & Oxide						
Iron(II) & Sulfide						
Potassium & Sulfate						
Silver & Nitrate						
Copper(II) & Hydroxide						
Ammonium & Carbonate						
Copper(I) & Phosphate						
Magnesium & Bromide						
Calcium & Acetate						

Data Table continued

Name: _____

Combining Ions
Iron(III) & Oxide
Copper(I) & Chromate
Sodium & Bicarbonate
Magnesium & Phosphate
Potassium & Cyanide
Aluminum & Sulfide

Ion Formula Chart

Names and Charges of Some Common Ions

1+	2+	3+
ammonium, NH_4^+ cesium, Cs^+ copper(I), Cu^+ gold(I), Au^+ hydrogen, H^+ lithium, Li^+ potassium, K^+ rubidium, Rb^+ silver, Ag^+ sodium, Na^+	barium, Ba^{2+} beryllium, Be^{2+} cadmium, Cd^{2+} calcium, Ca^{2+} chromium(II), Cr^{2+} cobalt(II), Co^{2+} copper(II), Cu^{2+} iron(II), Fe^{2+} lead(II), Pb^{2+} magnesium, Mg^{2+} mercury(I), Hg_2^{2+} mercury(II), Hg^{2+} nickel, Ni^{2+} strontium, Sr^{2+} tin(II), Sn^{2+} zinc, Zn^{2+}	aluminum, Al^{3+} chromium(III), Cr^{3+} cobalt(III), Co^{3+} gallium, Ga^{3+} gold(III) Au^{3+} iron(III), Fe^{3+}
		4+
		lead(IV), Pb^{4+} tin(IV), Sn^{4+}
1–	**2–**	**3–**
acetate, $C_2H_3O_2^-$ bromate, BrO_3^- bromide, Br^- chlorate, ClO_3^- chloride, Cl^- chlorite, ClO_2^- cyanide, CN^- dihydrogen phosphate, $H_2PO_4^-$ fluoride, F^- hydrogen carbonate, or bicarbonate, HCO_3^- hydrogen sulfate, HSO_4^- hydroxide, OH^- iodate, IO_3^- iodide, I^- nitrate, NO_3^- nitrite, NO_2^- permanganate, MnO_4^-	carbonate, CO_3^{2-} chromate, CrO_4^{2-} dichromate, $Cr_2O_7^{2-}$ hydrogen phosphate, HPO_4^{2-} oxide, O^{2-} oxalate, $C_2O_4^{2-}$ peroxide, O_2^{2-} selenide, Se^{2-} sulfate, SO_4^{2-} sulfide, S^{2-} sulfite, SO_3^{2-} tartrate, $C_4H_4O_6^{2-}$ telluride, Te^{2-} thiosulfate, $S_2O_3^{2-}$	borate, BO_3^{3-} nitride, N^{3-} phosphate, PO_4^{3-} phosphide, P^{3-}

Models of Cations

Na^+	Na^+	Na^+	Li^+	Li^+	Li^+
K^+	K^+	K^+	Ag^+	Ag^+	Ag^+
NH_4^+	NH_4^+	NH_4^+	Cu^+	Cu^+	Cu^+
Ca^{2+}	Ca^{2+}	Ca^{2+}	Cu^{2+}	Cu^{2+}	Cu^{2+}
Fe^{2+}	Fe^{2+}	Fe^{2+}	Mg^{2+}	Mg^{2+}	Mg^{2+}
Fe^{3+}	Fe^{3+}	Fe^{3+}			
Al^{3+}	Al^{3+}	Al^{3+}			

Models of Anions

Cl^-	Cl^-	Cl^-	OH^-	OH^-	OH^-
Br^-	Br^-	Br^-	$C_2H_3O_2^-$	$C_2H_3O_2^-$	$C_2H_3O_2^-$
NO_3^-	NO_3^-	NO_3^-	CN^-	CN^-	CN^-
S^{2-}	S^{2-}	S^{2-}	SO_4^{2-}	SO_4^{2-}	SO_4^{2-}
O^{2-}	O^{2-}	O^{2-}	CO_3^{2-}	CO_3^{2-}	CO_3^{2-}
HCO_3^-	HCO_3^-	HCO_3^-			
CrO_4^{2-}	CrO_4^{2-}	CrO_4^{2-}			
PO_4^{3-}	PO_4^{3-}	PO_4^{3-}			

Answers to Data Table

Combining Ions	Number of cations	Number of anions	Total + charge	Total – charge	Formula	Name of compound
1. Aluminum & Chloride Al^{3+} and Cl^-	1	3	+3	–3	$AlCl_3$	Aluminum chloride
2. Sodium & Oxide Na^+ and O^{2-}	2	1	+2	–2	Na_2O	Sodium oxide
3. Iron(II) & Sulfide Fe^{2+} and S^{2-}	1	1	+2	–2	FeS	Iron(II) sulfide
4. Potassium & Sulfate K^+ and SO_4^{2-}	2	1	+2	–2	K_2SO_4	Potassium sulfate
5. Silver & Nitrate Ag^+ and NO_3^-	1	1	+1	–1	$AgNO_3$	Silver nitrate
6. Copper(II) & Hydroxide Cu^{2+} and OH^-	1	2	+2	–2	$Cu(OH)_2$	Copper(II) hydroxide
7. Ammonium & Carbonate NH_4^+ and CO_3^{2-}	2	1	+2	–2	$(NH_4)_2CO_3$	Ammonium carbonate
8. Copper(I) & Phosphate Cu^+ and PO_4^{3-}	3	1	+3	–3	Cu_3PO_4	Copper(I) phosphate
9. Magnesium & Bromide Mg^{2+} and Br^-	1	2	+2	–2	$MgBr_2$	Magnesium bromide
10. Calcium & Acetate Ca^{2+} and $C_2H_3O_2^-$	1	2	+2	–2	$Ca(C_2H_3O_2)_2$	Calcium acetate

Answers to Data Table continued

Combining Ions	Number of cations	Number of anions	Total + charge	Total – charge	Formula	Name of compound
11. Iron(III) & Oxide Fe^{3+} and O^{2-}	2	3	+6	–6	Fe_2O_3	Iron(III) oxide
12. Copper(I) & Chromate Cu^{+} and CrO_4^{2-}	2	1	+2	–2	Cu_2CrO_4	Copper(I) chromate
13. Sodium & Bicarbonate Na^{+} and HCO_3^{-}	1	1	+1	–1	$NaHCO_3$	Sodium bicarbonate
14. Magnesium & Phosphate Mg^{2+} and PO_4^{3-}	3	2	+6	–6	$Mg_3(PO_4)_2$	Magnesium phosphate
15. Potassium & Cyanide K^{+} and CN^{-}	1	1	+1	–1	KCN	Potassium cyanide
16. Aluminum & Sulfide Al^{3+} and S^{2-}	2	3	+6	–6	Al_2S_3	Aluminum sulfide
17.						
18.						
19.						
20.						