Activity 3 Chemical Names and Formulas

GOALS

In this activity you will:

- Predict the charges of ions of some elements.
- Determine the formulas of ionic compounds.
- Write the conventional names of ionic compounds.
- Make observations to determine whether there is evidence that chemical changes occur on combining two ionic compounds.

What Do You Think?

Chemistry is the study of matter and its interactions. A great contribution to the study of chemistry was the discovery that all of the world is composed of elements and that there are approximately 100 elements in nature. The periodic table provides valuable information about each element.

- What information is provided for the element shown? What significance does this information have?

20	**1.0**
2	
Ca	
40.078	
$[Ar]4s^2$	
Calcium	

Record your ideas about these questions in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

1. The periodic table lists the elements in order of their atomic number. The atomic number is the number of protons (positively charged particles) in the nucleus of one atom of that element. For a neutral atom, the number of protons also equals the number of electrons (negatively charged particles).

What Do You Think?

The students' backgrounds will help them arrive at acceptable answers for these questions. They can use the periodic table in **Chapter 7** of this book to identify the elements' atomic number (Z), atomic mass (A), symbol, electron configuration, and state of matter.

Student Conceptions

Students do not understand what a formula represents – how to decode a formula, and especially what subscripts indicate. Students often want to insert a coefficient into the formula to balance the equation, without understanding how the chemical change occurs, or what the formula represents.

It is helpful to have students build simple compounds from a model kit or from gumdrops and toothpicks, and to rearrange the "atoms" for a chemical change by literally breaking and reforming bonds. Then have them represent this in writing and, finally, in symbolic form.

Teachers are fond of explaining ion formation in ways something like this: "The alkali metals easily ('love to') give up one electron each (to achieve noble gas electron configurations)." It is important to emphasize that all alkali metals require energy to be ionized.

The ingredients of many consumer products will list sodium or potassium. What the item actually contains are Na^+ and K^+ ions. Students are often unaware that elements and ions of the same elements have very different properties. For example, while sodium and potassium ions are necessary for life, the elemental substances are highly toxic.

Active Chemistry Cool Chemistry Show

Electrons are found outside the nucleus. A helium atom, with an atomic number of 2, has 2 protons in the nucleus and 2 electrons surrounding its nucleus.

For each of the following elements, write the symbol for the element and indicate the number of protons an atom of that element would have. (Refer to the periodic table.)

a) copper	b) sulfur
c) zinc	d) gold
e) oxygen	f) carbon
g) silver	h) chlorine
i) nitrogen	j) hydrogen
k) magnesium	l) iodine
m) iron	n) calcium
o) aluminum	p) sodium
q) potassium	r) lead

2. Elements can combine to form compounds. A compound results when two or more different elements bond. Some compounds are comprised of positive and negative ions that are bound by their mutual attraction. An ion is an atom that has lost or gained electrons, and therefore is charged because its protons and electrons no longer balance and cancel each other. For example, when a chlorine atom gains one electron, it becomes a chloride ion with a charge of –1 (remember electrons have negative charge). When a sodium atom loses one electron, it becomes a sodium ion with a charge of +1 (because now there is one more proton than the number of electrons). The resulting compound is sodium chloride (NaCl), which you know as table salt and it is an ionic compound.

   a) The chemical formula for the compound of potassium and bromine is KBr. Look at where potassium is located on the periodic table (Group 1) and also where bromine is located (Group 17). Each of these has an ionic charge of 1. Potassium is +1, bromine is –1. List four other compounds that are created from elements in Group 1 combining with elements in Group 17.

   b) Magnesium forms an ion with a charge of +2 and oxygen forms an oxide ion with a –2 charge. The chemical formula for magnesium oxide is MgO. List four other compounds that are created from elements in Group 2 combining with elements in Group 16.

3. If the values of the charge on a positive ion and a negative ion are the same, the formula of the resulting compound is simply the chemical symbols of each element. If the values of the charge on a positive ion and a negative ion are not the same, subscripts can be used to balance them. For example, aluminum loses 3 electrons to become an ion with a charge of +3. An iodine atom gains only 1 electron to form an ion with a charge of –1. It takes 3 iodine atoms to accept the 3 electrons given up by aluminum. This is reflected in the formula AlI_3. (Note where the 3 is placed for the 3 iodine atoms.) Another example is $CaCl_2$, where 2 chloride ions (each gaining one electron) and one calcium ion (having lost 2 electrons) combine.

   Write the chemical formula and name for the compound formed when the following pairs of elements

Investigate

Teaching Suggestions and Sample Answers

1.	**a)**	Cu (29)	**b)**	S (16)	**c)**	Zn (30)
	d)	Au (79)	**e)**	O (8)	**f)**	C (6)
	g)	Ag (47)	**h)**	Cl (17)	**i)**	N (7)
	j)	H (1)	**k)**	Mg (12)	**l)**	I (53)
	m)	Fe (26)	**n)**	Ca (20)	**o)**	Al (13)
	p)	Na (11)	**q)**	K (19)	**r)**	Pb (82)

2. **a)** KBr. Students should realize that potassium belongs to the same family as sodium, lithium, and cesium. Bromine belongs to the same family as chlorine, iodine, and fluorine. The other formulas are: LiF, LiCl, LiBr, LiI, NaF, NaBr, NaI, KF, KCl, KI, CsF, CsCl, CsBr, and CsI. Due to their limited understanding of the periodic table, students may require help.

b) MgO. The alkaline earth metals want to lose two electrons and will have an ionic charge of 2+ and the group 16 (or VIA) family wants to gain two electrons and will have an ionic charge of 2−. Examples of these ion combinations are: BeO, BeS, BeSe, BeTe, MgS, MgSe, MgTe, CaO, CaS, CaSe, CaTe, SrO, SrS, SrSe, SrTe, BaO, BaS, BaSe, and BaTe. Make certain that they understand the net charge on the ionic compound must add up to be zero.

3. **a)** CaO. Calcium is in the same family as magnesium (alkaline earth metals). The name is calcium oxide.

b) AlF_3. Aluminum has a 3+ charge and fluorine is a halogen with a 1– charge. The name is aluminum fluoride.

c) B_2O_3. Boron is in the same family as aluminum and should then have a +3 charge and the oxygen has a 2– charge. Then $2(3+) + 3(1–) = 0$. This point is actually debatable, because boron, carbon and silicon really do not form ions. However, the formation of boron compounds seems to indicate that it occurs in a 3+ state similar to that of aluminum. Some call the oxidation state of boron a fictitious "oxidation state" so that it won't contradict the general nonmetal tendency to gain electrons (while metals lose electrons). The name is boron oxide.

d) Sr_3N_2. Strontium is an alkaline earth metal with a charge of 2+ and nitrogen has a charge of 3–. Students may struggle here, due to their inexperience with nitrogen. The name is strontium nitride

e) BaSe. Barium is an alkaline earth metal and selenium, in the same family as oxygen and sulfur, has a 2– charge. The name is barium selenide.

are combined:

a) calcium and oxygen

b) aluminum and fluorine

c) boron and oxygen

d) strontium and nitrogen

e) barium and selenium

4. Some compounds, like baking soda, sodium hydrogen carbonate ($NaHCO_3$), incorporate polyatomic ions. Polyatomic ions are made up of several elements joined together. In the case of baking soda, the sodium (Na) ion has a charge of +1 and the hydrogen carbonate ion (the polyatomic ion HCO_3) has a charge of –1. (Note: hydrogen carbonate ion is also called bicarbonate ion.)

   Write the chemical formula for each compound below.

   a) potassium nitrate (nitrate: NO_3^{-1})

   b) barium sulfate (sulfate: SO_4^{-2})

   c) potassium sulfate

   d) sodium acetate (acetate: $C_2H_3O_2^{-1}$)

   Write the name for each compound below.

   e) $(NH_4)_2SO_4$ (ammonium: NH_4^{+1})

   f) $Al_2(CO_3)_3$

   g) $LiHCO_3$

   h) HNO_3

5. You have learned about ionic compounds that are made from positive and negative ions. In another class of compounds, called molecules, the atoms are bound by electrons being mutually attracted to the protons in adjacent atoms. These bonds are called covalent bonds, because atoms are sharing electrons. It is often useful to imagine, however, that the atoms inside of molecules are charged. These "imagined charges" are called oxidation numbers.

   a) The formula for carbon dioxide is CO_2. If you pretend this is an ionic compound, what is the charge (oxidation number) of carbon?

   b) Carbon monoxide is CO. What is the oxidation number of carbon now?

   c) Explain how you arrived at your answers.

You must wear safety goggles and a lab apron.

6. Do chemical changes occur every time reactants are mixed? Let's find out. Read the directions for this step so you can prepare a data table to record and describe all that you observe.

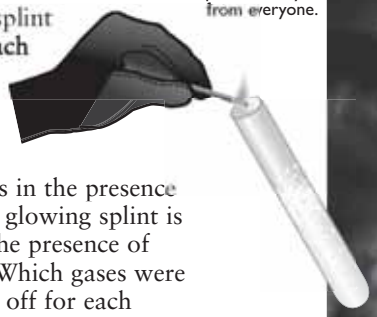
   Put equal amounts of baking soda, crushed Alka-Seltzer™ tablet, and baking powder into three separate test tubes respectively. Be sure to label the test tubes!

   Add equal amounts of water to each.

   a) Record your observations. (You should now know the chemical formula for baking soda $NaHCO_3$.)

   b) Place a glowing splint into the top of each test tube. Make note of what happens. A glowing splint bursts into flames in the presence of oxygen, and a glowing splint is extinguished in the presence of carbon dioxide. Which gases were most likely given off for each reaction?

Hold the splint with tongs or wear a heatproof glove. Be sure the mouth of the test tube is pointed away from everyone.



4. Suggestion: Take some time to explain nomenclature and how to name compounds and acids before students start this section.

Chem Tip:
Produce a table of polyatomic ions that students can use in writing the correct formulas and names:

acetate, CH_3COO^- or CH_3CO^{2-}	carbonate, CO_3^{2-}
chlorate, ClO_3^-	chlorite, ClO_2^-
chromate, CrO_4^{2-}	cyanide, CN^-
dichromate, $Cr_2O_7^{2-}$	dihydrogen phosphate, $H_2PO_4^-$
hydrogen carbonate (bicarbonate), HCO_3^-	hydrogen sulfate (bisulfate), HSO_4^-
hydrogen sulfite (bisulfite), HSO_3^-	hydroxide, OH^-
hypochlorite, ClO^- (or OCl^-)	iodate, IO_3^-
monohydrogen phosphate, HPO_4^{2-}	nitrate, NO_3^-
nitrite, NO_2^-	oxalate, $C2O_4^{2-}$
perchlorate, ClO_4^-	permanganate, MnO_4^-
peroxide, O_2^{2-}	phosphate, PO_4^{3-}
silicate, SiO_3^{2-}	sulfate, SO_4^{2-}
sulfite, SO_3^{2-}	tartrate, $C_4H_4O^{2-}$
tetraborate, $B_4O_7^{2-}$	thiocyanate, SCN^-
thiosulfate, $S_2O_3^{2-}$	
ammonium, NH_4^+	hydronium ion, H_3O^+ (in aqueous solutions)

a) KNO_3. Notice that the anion name ends with the name of the ion that was assigned.

b) $BaSO_4$.

c) K_2SO_4.

d) $NaCH_3COO$ or $NaCH_3CO_2$. The first formula gives you the structural formula for sodium acetate and many chemists prefer that you use this one. However, the second form is certainly acceptable.

e) $(NH_4)_2SO_4$. Ammonium sulfate is unique because the ammonium ion that is in the parentheses with the subscript 2.

f) $Al_2(CO_3)_3$. Aluminum carbonate also requires some careful bookkeeping. The aluminum has a 3+ charge and the carbonate has a 2– charge. Since formulas cannot have fractions, then the common transfer must be 6 electrons.

g) $LiHCO_3$. Lithium hydrogen carbonate is similar to sodium hydrogen carbonate.

h) HNO_3 is nitric acid. The students may name this as hydrogen nitrate, which is fine. Show them that sulfuric acid is H_2SO_4 and that we seldom call it dihydrogen sulfate, even though that would also be acceptable. Another nomenclature example is water. We could also call it dihydrogen oxide or hydrogen oxide.

5. a) Carbon would have the oxidation number of +4 since each oxygen atom wants to gain electrons. Carbon does have 4 valence electrons and will be willing to share these 4 electrons with the two oxygen atoms.

b) The carbon will now have the oxidation number of +2 and only one oxygen is needed to balance it. This compound is interesting in that it does not satisfy the octet rule. Carbon monoxide is unstable and will often combine with something else in order to gain stability.

c) See discussion above.

6. - 10.

	Water	**Vinegar**	**Ammonia**	**With heat**
Baking Soda	Few bubbles	Bubbles	Some bubbles	More bubbles
Baking Powder	Few bubbles	Bubbles	Could not see any bubbles	More bubbles
Alka Seltzer	Fast reaction Bubbles	Bubbles	Few bubbles then it stopped	Much more activity

Discussion: Baking soda is sodium hydrogen carbonate, baking powder is a mixture of corn starch, monocalcium phosphate and sodium hydrogen carbonate, and Alka Seltzer contains aspirin, citric acid and sodium hydrogen carbonate.

The glowing splint went out which indicated that the gas is probably carbon dioxide.

Chem Tip:
Students will ask why the Alka-Seltzer tablets give off carbon dioxide when they place them in water. The answer is that water activates the citric acid contained in the tablets. Ask students which solvent most effectively released the gas from baking soda (vinegar, which they know to contain acetic acid) then allow them to examine the Alka-Seltzer label, where they will see that citric acid is an ingredient.

NOTES

Active Chemistry Cool Chemistry Show

7. When the reactions have stopped completely, your teacher will put three of the test tubes in a beaker of boiling water. Observe what happens.
   a) Make a note of the results in your *Active Chemistry* log.
8. Repeat **Steps 6** and **7** using clean test tubes, fresh reagents, and instead of water add
   • vinegar • ammonia.
9. Your teacher will give you a small amount of a white powdered substance that is either baking soda, Alka-Seltzer, or baking powder.
   a) Write down the number of your unknown and determine which of the three substances it is. Provide evidence to support your conclusion.
10. Clean all apparatus and the laboratory bench when you are finished. Dispose of all chemicals as directed by your teacher. Wash your hands.

ChemTalk

FORMING COMPOUNDS

Ionic Compounds

There are certainly more than 100 physically different materials in this world. With approximately 100 elements, how is it possible to have such a variety of materials? How is it possible to invent new materials for clothing, building, and food? Elements can combine to form compounds. A **compound** results when two or more different elements bond.

Some compounds are comprised of positive and negative **ions** that are bound by their mutual attraction. An ion is an atom that has lost or gained electrons, and therefore is charged because its protons and electrons no longer balance and cancel each other. For example, when an iodine atom gains one electron, it becomes a iodide ion with a charge of −1 (remember electrons have negative charge). A negatively charged ion is called an **anion**. When a potassium atom loses one electron, it becomes a potassium ion with a charge of +1 (because now there is one more proton than the number of electrons). A positively charged ion is called a **cation**. The resulting **ionic compound** is potassium iodide (KI). Potassium iodide is added to most of the table salt you use. Table salt (NaCl) is another example of an ionic compound.

Chem Words

compound: a material that consists of two or more elements united together in definite proportion

ion: an electrically charged atom or group of atoms that has acquired a net charge, either negative or positive

anion: a negatively charged ion

cation: a positively charged ion

ionic compound: a compound consisting of positive or negative ions

NOTES

If you refer to a periodic table you will notice that elements that form positive ions are on the left side of the table and elements that form negative ions are on the right side. Metals combine with nonmetals to form ionic compounds. Also, when two elements combine the name given the negative ion will end with -ide, and the compound is named with the metal or positive ion first. This is true for binary compounds, for example: sodium chloride, potassium bromide, and magnesium oxide. When dissolved in water, you would find that ionic compounds conduct electricity. In this activity you also investigated some compounds formed with **polyatomic ions**. Polyatomic ions are made up of several elements joined together. For example, Milk of Magnesia™ incorporates the hydroxide ion (OH^{-1}) with the magnesium ion to form magnesium hydroxide, $Mg(OH)_2$. The following table lists some polyatomic ions and their charges.

Polyatomic Ions		
nitrate	NO_3^{-1}	negative one, –1
sulfate	SO_4^{-2}	negative two, –2
hydroxide	OH^{-1}	negative one, –1
carbonate	CO_3^{-2}	negative two, –2
hydrogen carbonate	HCO_3^{-1}	negative one, –1
acetate	$C_2H_3O_2^{-1}$	negative one, –1
ammonium	NH_4^{+1}	positive one, +1

Molecular Compounds

You also learned about **molecular compounds** in this activity. When two atoms of molecular elements come together, neither atom gains nor loses an electron. Instead, the bonding electrons are shared between the two atoms. The mutual attraction of two nuclei for a shared pair of bonding electrons is called a **covalent bond**. Molecular compounds are usually formed by nonmetal-nonmetal combinations. You would find that when dissolved in water, molecular compounds do not conduct electricity.

With covalent bonds you also found that it is often useful to imagine that the atoms inside of molecules are charged. These "imagined

Chem Words

polyatomic ion: an ion that consists of 2 or more atoms that are covalently bonded and have either a positive or negative charge

molecular compound: two or more atoms bond together by sharing electrons (covalent bond)

covalent bond: a bond formed when two atoms combine and share their paired electrons with each other

Checking Up

1. If there are only about 100 elements in this world, why are there so many different materials?
2. What is an ion?
3. How are ionic compounds formed?
4. What is a polyatomic ion? Provide an example of a compound formed with a polyatomic ion.
5. How are molecular compounds formed?
6. Distinguish between an ionic and a covalent bond.

ChemTalk

Checking Up

1. The ionic compounds can form numerous binary compounds, complex compounds, and compounds that have numerous atoms in different arrangements. Covalent compounds have all types of combinations. There are millions of organic compounds.

2. If an atom gains or loses electrons it will assume a negative or positive charge. This new state is called an ion. Notice that only electrons are moving and no changes occur in the nucleus or the number of protons.

3. Ionic compounds form due to an electrostatic attraction between the positive and negative ions. The charge on the positive ion must balance with the charge on the negative ion. If the positive ion (cation) has a charge of 2+ and the negative ion (anion) has a charge of 1–, then you would need two anions to balance the 2+ charge of the cation.

4. A polyatomic ion is a combination of atoms with a net ionic charge. For example, carbonate anion has a 2– charge and it is the combination of one carbon and 3 oxygen atoms (CO_3^{2-}). Potassium carbonate would be K_2CO_3.

5. Molecular compounds are formed by the sharing of electrons. Neither atom in the bond can totally pull an electron from the other atom as occurs with ionic bonds. Water is a good example of a molecular compound. The hydrogen and oxygen bond by sharing a pair of electrons. Since most compounds strive for 8 surrounding electrons (with the exception of hydrogen and helium), then water is formed of two hydrogen atoms covalently bonded with oxygen. When hydrogen shares its two electrons, oxygen has the desired 8 electrons surrounding it.

6. Ionic compounds are held together by electrostatic attraction, and covalent bonds form from electrons shared between atoms.

Chem Words

oxidation number: a number assigned to an element in a compound designating the number of electrons the element has lost, gained, or shared in forming that compound

charges" are used as a type of bookkeeping and are called **oxidation numbers**. In both ionic compounds and molecular compounds the atoms achieve a stable state, similar to the noble gases.

Reflecting on the Activity and the Challenge

In this activity you have learned how to write the formulas for many compounds and how to name some compounds. You have also investigated both ionic and molecular compounds. As you prepare your presentation for your **Cool Chemistry Show**, you will want to include your knowledge of formulas, the names of compounds, and the different kinds of compounds. Remember that you will be providing the teacher with an explanation of why you included certain demonstrations, and you will also want to include explanations that are grade-appropriate. Think about how much information you will need to provide for each demonstration.

Chemistry to Go

1. Write the chemical formula and name for the compound formed when the following pairs of elements are combined:
   a) sodium and bromine
   b) potassium and sulfur
   c) magnesium and chlorine
   d) cesium and iodine
   e) aluminum and oxygen

Chemistry to Go

1. **a**) NaBr, sodium bromide
   b) K_2S, potassium sulfide
   c) $MgCl_2$, magnesium chloride
   d) CsI, cesium iodide
   e) Al_2O_3, aluminum oxide

2. Write the chemical formula for each of the following.

   a) hydrogen nitrate (nitric acid)
   b) ammonium hydroxide
   c) calcium carbonate
   d) hydrogen acetate (acetic acid)

3. a) Write the chemical formula for copper (II) sulfate. The (II) indicates that this copper ion has a +2 charge.

   b) Oxygen ions usually have a negative 2 charge (–2). How would formulas for iron (II) oxide differ from iron (III) oxide?

4. You may have noticed that all the elements in the first column of the periodic table (the alkali metals: lithium, sodium, potassium, rubidium, and cesium) have a +1 charge when they combine with negative ions. Another group of positive ions are the alkaline earth metals (beryllium, magnesium, calcium, strontium, and barium), located in the second column of the periodic table. What charge is typical for ions of the alkaline earth metals?

5. The formula for sodium phosphate is Na_3PO_4. What is the charge on the polyatomic phosphate ion? What information did you use to arrive at your answer?

6. When you write the formula for sodium hydroxide, you do not have to put parentheses around the hydroxide polyatomic ion. However, when writing the formula for aluminum hydroxide, you must put parentheses around the hydroxide polyatomic ion.

   a) Write each formula.

   b) Explain why the parentheses are necessary for aluminum hydroxide.

7. a) If the chemical formula for iron (III) chloride is $FeCl_3$, what is the chemical formula for iron (III) nitrate?

   b) If the chemical formula for lead (II) oxide is PbO, what is the chemical formula for lead (II) sulfate?

   c) If the chemical formula for silver chloride is AgCl, what is the chemical formula for silver nitrate?

8. In **Activity 2**, you tested various compounds for chemical changes. (Barium nitrate, sodium hydroxide, sodium hydrogen carbonate, copper (II) sulfate, potassium iodide, silver nitrate, iron (III) nitrate, and hydrochloric acid.) Write the chemical formulas for each of the reactants.

Preparing for the Chapter Challenge

Review any chemical reactions you are considering including in your **Cool Chemistry Show**. Write the formulas of any compounds that you plan to use.

2. **a)** HNO_3, which is usually called nitric acid.
b) NH_4OH; note that no parentheses are required since the two ionic groups combine in a 1:1 ratio.
c) $CaCO_3$
d) HCH_3COO or HCH_3CO_2, usually called acetic acid (acetic acid is found in vinegar solution).

3. **a)** $CuSO_4$; The International Union of Pure and Applied Chemists (IUPAC) advocates the use of this naming system. The old common name system created some problems and confusion. In this case, copper (II) sulfate would be called cupric sulfate.
b) Iron (II) oxide is FeO and iron (III) oxide is Fe_2O_3. Iron (II) oxide was formerly called ferrous oxide and iron (III) oxide was called ferric oxide.

4. The alkaline earth metals have the ionic charge of 2+. They will lose two electrons in order to achieve a noble gas configuration.

5. Since we know that the charge on sodium is 1+ and it took three sodium atoms to combine with the phosphate anion, then the charge on the phosphate anion must be 3–.

6. **a)** Sodium hydroxide is NaOH and aluminum hydroxide is $Al(OH)_3$.
b) Aluminum has a 3+ charge and the hydroxide ion has a 1– charge, so 3 hydroxide ions are needed to balance the aluminum ion. It would be incorrect to put the 3 after the hydrogen atom of hydroxide without parentheses since that would apply only to the hydrogen atom and not to the hydroxide ion.

7. **a)** If iron chloride is $FeCl_3$ then the iron must have a 3+ charge. The nitrate anion has a charge of 1–, which is the same as a chloride anion. Therefore, the correct formula for iron (III) nitrate is $Fe(NO_3)_3$.
b) If the formula for lead oxide is PbO, then the lead must have a 2+ charge. Since the sulfate anion has a charge of 2–, then the correct formula for lead (II) sulfate is $PbSO_4$.
c) If the formula for silver chloride is AgCl, then the silver must have a charge of 1+. Since the nitrate anion has a charge of 1–, then the correct formula for silver nitrate is $AgNO_3$.

8. Barium nitrate: $Ba(NO_3)_2$
Sodium hydroxide: NaOH
Sodium hydrogen carbonate or sodium bicarbonate: $NaHCO_3$
Copper (II) sulfate: $CuSO_4$
Potassium iodide: KI
Silver nitrate: $AgNO_3$
Iron (III) nitrate: $Fe(NO_3)_3$
Hydrochloric acid: HCl: (Note that when hydrogen chloride is dissolved in water it is called hydrochloric acid.)