Compounds and Their Bonds 9

LABORATORY GOALS

- Write the electron-dot symbol for an atom and an ion.
- Write a correct formula and name of an ionic compound.
- Write a correct formula and name of an ionic compound containing a polyatomic ion.
- Write a correct formula and name of a molecular compound.
- Use the electron-dot formula of a compound to predict its shape and polarity.

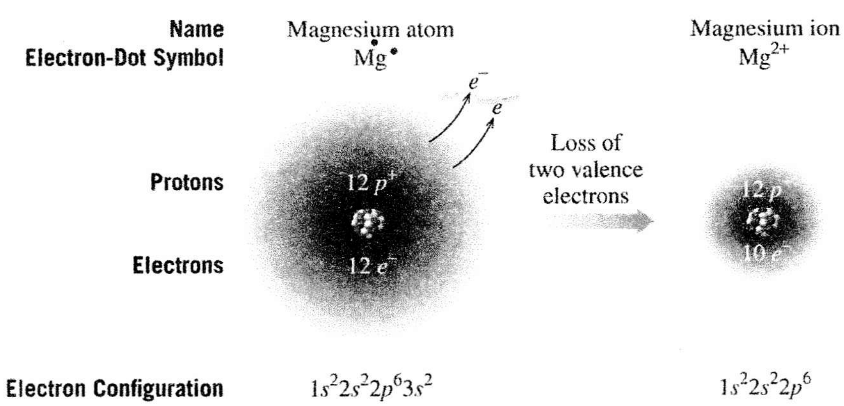
LAB INFORMATION

Time:	2–3 h
Comments:	Tear out the report sheets and place them beside the matching procedures.
Related Topics:	Ions, ionic bonds, electron-dot symbols, electron-dot formulas, ionic compounds, covalent bonds, molecular compounds

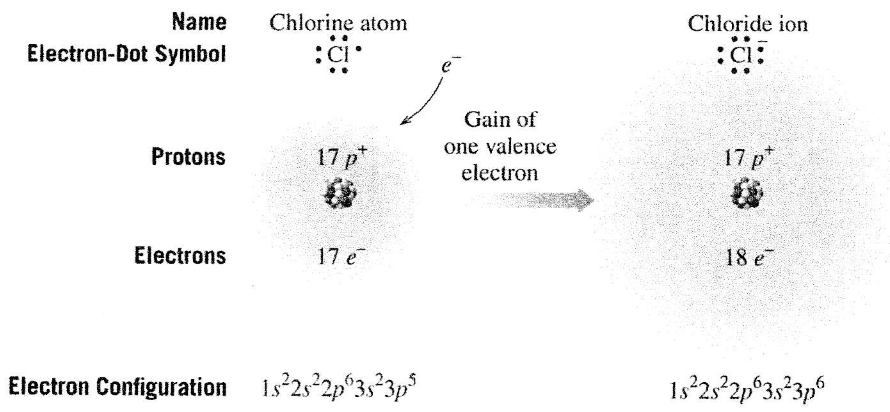
CHEMICAL CONCEPTS

A. Ions: Transfer of Electrons

When atoms of metals in Groups 1A (1), 2A (2), or 3A (13) react with atoms of nonmetals in Groups 5A (15), 6A (16), or 7A (17), the metals lose electrons and the nonmetals gain electrons in their valence shells. We can predict the number of electrons lost or gained by looking at the electron configurations of the atoms. For example, magnesium, which has an electron configuration $1s^22s^22p^63s^2$, has two valence electrons. It loses those two electrons to attain an octet with an electron arrangement of $1s^22s^22p^6$. The result is a *magnesium ion* with a charge of 2+. As a positive ion, it keeps the same name as the element.

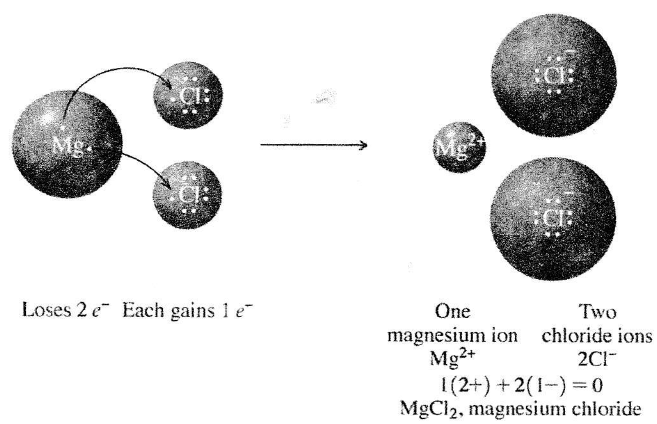


When metals combine with nonmetals (5, 6, or 7 valence electrons), nonmetals gain electrons to obtain a stable electron configuration. For example, chlorine, which has an electron configuration $1s^22s^22p^63s^23p^5$, has seven valence electrons. By gaining one valence electron, it becomes stable with an electron configuration of $1s^22s^22p^63s^23p^6$. The result is a negatively charged *chloride ion* with a charge of 1–. In the name of a binary compound with two different elements, the name of the negative ion ends in *ide*.



B. Ionic Compounds and Formulas

A *compound* consists of two or more different elements that are chemically combined. Most atoms combine by forming stable electron configurations. For example, the attractions between the positively charged Mg^{2+} ions and the negatively charged Cl^- ions are called ionic bonds.



The group number 1A–8A on the periodic table can be used to determine the ionic charges of the representative elements.

Group number	**1A (1)**	**2A (2)**	**3A (13)**	**4A (14)**	**5A (15)**	**6A (16)**	**7A (17)**	**8A (18)**
Valence electrons	$1\,e^-$	$2\,e^-$	$3\,e^-$	$4\,e^-$	$5\,e^-$	$6\,e^-$	$7\,e^-$	$8\,e^-$
Electron change	lose 1	lose 2	lose 3	none	gain 3	gain 2	gain 1	no change
Ionic charge	1+	2+	3+	none	3–	2–	1–	none

To write an ionic formula, we use charge balance to determine the smallest number of positive and negative ions that give an overall charge of zero. For example, an overall charge of zero is obtained by using two Cl^- ions to match the charge of the Mg^{2+} ion.

$$1\,(2+) + 2(-1) = 0$$

The number of each type of ion needed for charge balance gives the subscripts in the formula for the compound $MgCl_2$. (The subscript 1 for Mg is understood.) In any ionic formula, only the symbols and subscripts are written, not their ionic charges.

$$Mg^{2+} + 2\,Cl^- = MgCl_2 = 0$$

C. Metals in Ionic Compounds with Variable Charge

Most of the transition metals can form more than one kind of positive ion. For example, iron forms two ions, Fe^{2+} and Fe^{3+}. To distinguish between the two ions, a Roman numeral that gives the ionic charge is written after the element name. The Roman numeral is always included within the parentheses in the names of compounds that form two or more positive ions. It is never included in the chemical formula. (see Table 9.1).

TABLE 9.1 Some Ions of the Transition Elements

Ion	Names	Compound	Names
Fe^{2+}	Iron(II) ion	$FeCl_2$	Iron(II) chloride
Fe^{3+}	Iron(III) ion	$FeCl_3$	Iron(III) chloride
Cu^{+}	Copper(I) ion	CuCl	Copper(I) chloride
Cu^{2+}	Copper(II) ion	$CuCl_2$	Copper(II) chloride

Among the transition metals, a few elements (zinc, silver, and cadmium) form only a single type of ion. Thus, they are not variable and we do not need to write a Roman numeral as part of their names.

Zn^{2+} zinc ion Ag^{+} silver ion Cd^{2+} cadmium ion

On the other hand, there are two metals (tin and lead) in Group 4A (14) that have variable charges and require Roman numerals.

Sn^{2+} tin(II) ion and Sn^{4+} tin(IV) ion Pb^{2+} lead(II) ion and Pb^{4+} lead(IV)

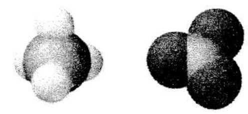
D. Polyatomic Ions

A compound that consists of three or more kinds of atoms will contain a polyatomic ion. A polyatomic ion is a group of covalently bonded atoms with an overall charge. That charge, which is usually negative, is the result of adding electrons to complete octets. Some examples of polyatomic ions are given in Table 9.2. The most common ion is named by replacing the ending of the name for the nonmetal with *ate*. The *ite* ending has one oxygen less than the most common form of the ion. Ammonium ion, NH_4^{+}, is positive because its group of atoms lost one electron.

TABLE 9.2 Some Polyatomic Ions*

Polyatomic Ion	Name	Polyatomic Ion with One Less Oxygen	Name
NH_4^{+}	ammonium		
OH^{-}	hydroxide		
NO_3^{-}	**nitrate**	NO_2^{-}	nitrite
ClO_3^{-}	**chlorate**	ClO_2^{-}	chlorite
		ClO^{-}	hypochlorite
CO_3^{2-}	**carbonate**		
HCO_3^{-}	hydrogen carbonate (bicarbonate)		
SO_4^{2-}	**sulfate**	SO_3^{2-}	sulfite
HSO_4^{-}	hydrogen sulfate (bisulfate)	HSO_3^{-}	hydrogen sulfite (bisulfite)
PO_4^{3-}	**phosphate**	PO_3^{3-}	phosphite

*Polyatomic ions and names in bold are the most common ions.



NH_4^+ Ammonium ion NO_3^- Nitrate ion

To write a formula with a polyatomic ion, we determine the number of each type of ion needed for charge balance just as we did with the simple ions. When two or more polyatomic ions are needed, the formula of the polyatomic ion is enclosed in parentheses and the subscript placed outside. For example, the formula of calcium nitrate, which contains the ions Ca^{2+} and NO_3^-, is $Ca(NO_3)_2$.

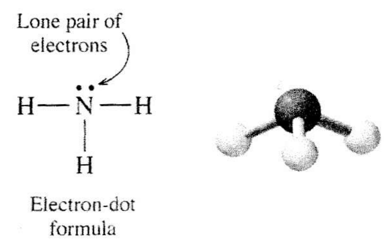
Subscript for charge balance

$Ca(NO_3)_2$ Calcium nitrate

Parentheses enclose polyatomic ion

E. Molecular Compounds: Sharing Electrons

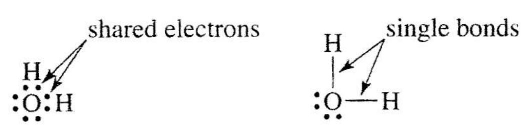
In a molecular compound, octets are achieved by sharing electrons between two nonmetals in Groups 4A (14), 5A (15), 6A (16), or 7A (17). For example, nitrogen in Group 5A (15) has five valence electrons, one electron pair and three single electrons. A molecule of NH_3 forms when the three unpaired electrons are each shared with the unpaired electrons of three H atoms. The sharing of one pair of electrons is called a *single bond*.



▲ A molecule of NH_3 contains three single bonds between the N atom and three H atoms.

The electron-dot formula of a molecular compound is drawn by sharing the valence electrons until each atom has a complete octet. For example, in water (H_2O), the O atom shares two unpaired electrons with two H atoms. The O atom now has an octet and both H atoms are stable with two valence electrons.

Electron–Dot Formula for H_2O

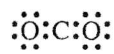


Sometimes, more than one pair of electrons is shared between the central atom and its bonded atoms. For example, we use the following steps to draw the electron-dot formula for CO_2, in which C is the central atom:

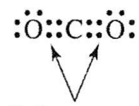
1. The arrangement of the atoms is O C O.
2. The C atom has 4 valence electrons and each of the O atoms has 6 valence electrons. Thus there are 16 (4 + 6 + 6) valence electrons that can be used to form octets in CO_2.
3. Attach each O atom to the central C atoms using a pair of electrons.

O:C:O

4. Place the remaining 12 electrons (16 – 4) around the C and O atoms.



Because the octet for the C atom is not complete, one electron pair from each O atom is shared with the C atom. This gives two double bonds in the CO_2 molecule by using 16 valence electrons.



O=C=O

sharing two pairs of electrons makes double bonds

Naming Molecular Compounds

Molecular compounds with two nonmetals are named by using *prefixes*, which state the number of atoms of each element in the compound (see Table 9.3). The first nonmetal is named by its element name; the second ends in *ide*. The first eight prefixes are *mono* (1), *di* (2), *tri* (3), *tetra* (4), *penta* (5), *hexa* (6), *hepta* (7), and *octa* (8). Usually the prefix mono is not shown, with the exception of carbon monoxide.

TABLE 9.3 Some Formulas and Names of Molecular Compounds

Formula	Name
CO	carbon **mono**xide
CO_2	carbon **di**oxide
PCl_3	phosphorus **tri**chloride
N_2O_4	**di**nitrogen **tetr**oxide (drop *a* in a double vowel)
SCl_6	sulfur **hexa**chloride

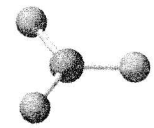
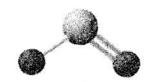
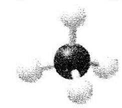
F. Electron-Dot Formulas and Shape

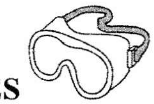
The shape of a molecule or an ion can be described as linear, bent, trigonal planar, tetrahedral, or trigonal pyramidal. The valence shell electron-pair repulsion (VSEPR) model indicates that the bond angles in a molecule or ion are determined when the valence electrons in bonds and lone pairs are as far apart as possible. Counting the shared pairs and lone pairs determines the electron-group arrangement. Only the atoms bonded to the central atom determine the shape (see Table 9.4).

Polar and Nonpolar Molecules

When the electronegativity difference is 0.5 to 1.8 between the central atom and an attached atom, the bond is polar. If the polar bonds in a molecule are symmetrical and the dipoles cancel, the molecule itself is nonpolar. When the dipoles do not cancel, the molecule or ion is polar.

TABLE 9.4 Shapes for a Central Atom with Two, Three, and Four Bonded Atoms

Electron Groups	Electron-Group Arrangement	Bonded Atoms	Lone Pairs	Bond Angle	Shape	Example	Three-Dimensional Model
2	Linear	2	0	180°	Linear	$BeCl_2$	
3	Trigonal Planar	3	0	120°	Trigonal planar	BF_3	
		2	1	120°	Bent	SO_2	
4	Tetrahedral	4	0	109°	Tetrahedral	CH_4	
		3	1	109°	Trigonal pyramidal	NH_3	
		2	2	109°	Bent	H_2O	

EXPERIMENTAL PROCEDURES  *GOGGLES REQUIRED!*

A. Ions: Transfer of Electrons

For each atom and ion, complete the following in the table:

1. electron configuration
2. electron-dot symbol
3. number of electrons lost or gained
4. electron configuration for each ion
5. ionic charge
6. symbol, including charge
7. name of the ion

B. Ionic Compounds and Formulas

Materials: Display of compounds, Internet, reference manuals

1. **Physical properties**

   From the display of compounds, describe the appearance of sodium chloride, NaCl.

   Using the Internet or a reference manual, record the density and the melting points of sodium chloride.

2. **Formulas of ionic compounds**

   Using the periodic table, write the positive and negative ions and the correct formula of each compound.

3. **Names of ionic compounds**

   Using the formula of each ionic compound, write the positive and negative ions and the correct name.

C. Metals in Ionic Compounds with Variable Charge

Materials: Display of compounds, Internet, reference manuals

1. **Physical properties**

   From the display of compounds, describe the appearance of iron(III) chloride, $FeCl_3$.

   Using the Internet or a reference manual, record the density and the melting points of iron(III) chloride.

2. **Formulas of ionic compounds**

   From the name, write the positive and negative ions and the correct formula of each compound.

3. **Names of ionic compounds**

   From the formula of each compound, write the positive and negative ions, and the name of the formula. Be sure to indicate the ionic charge as a Roman numeral if the transition metal has a variable valence.

D. Polyatomic Ions

Materials: Display of compounds, Internet, reference manuals

1. **Physical properties**

   From the display of compounds, describe the appearance of potassium carbonate, K_2CO_3.

   Using the Internet or a reference manual, record the density and the melting points of potassium carbonate.

2. **Formulas of ionic compounds**

   From the name, write the positive ion and negative polyatomic ion and the correct formula of each compound. Be sure to use parentheses when two or more polyatomic ions are needed.

3. **Names of ionic compounds**

   From the formula of each ionic compound, write the positive and negative ions (polyatomic) and the name of the compound. Be sure to indicate the ionic charge as a Roman numeral if the transition metal has a variable valence.

E. Molecular Compounds: Sharing Electrons

Materials: Display of compounds, Internet, reference manuals

1. **Physical properties**

   From the display of compounds, describe the appearance of water, H_2O.

   Using the Internet or a reference manual, record the density and the melting points of water.

2. **Formulas of molecular compounds**

   From the name, write the correct formula of the molecular compound using prefixes as subscripts.

3. **Names of molecular compounds**

   Name each molecular compound, using prefixes to indicate two or more atoms of an element.

F. Electron-Dot Formulas and Shape

Materials: Molecular model kit

Obtain a molecular model kit and build a model of each of the molecules in the report sheet, then complete the following for each:

1. Draw the electron-dot formula.
2. Count the electron groups around the central atom.
3. Use VSEPR to determine the electron-group arrangement.
4. Count the number of atoms bonded to the central atom.
5. Identify the molecular shape.
6. Indicate if the molecules listed would be polar or nonpolar.

Date ______________________ Name ______________________

Section ______________________ Team ______________________

Instructor ______________________ ______________________

Pre-Lab Study Questions | 9

1. Where are the valence electrons in an atom?

2. How are positive and negative ions formed?

3. Why are electrons shared in molecular compounds?

4. How do the names of molecular compounds differ from the names of ionic compounds?

5. What are polyatomic ions?

6. How does the number of bonded atoms around a central atom determine its shape? Include examples in your answer.

Date ______________________ Name ______________________

Section ______________________ Team ______________________

Instructor ______________________ ______________________

REPORT SHEET | LAB

Compounds and Their Bonds | 9

A. Ions: Transfer of Electrons

Element	Atomic Number	1. Electron Configuration of Atom	2. Electron-Dot Symbol	3. Loss or Gain of Electrons	4. Electron Configuration of Ion	5. Ionic Charge	6. Symbol of Ion	7. Name of Ion
Sodium	11	$1s^22s^22p^63s^1$	Na•	lose 1 e^-	$1s^22s^22p^6$	1+	Na^+	Sodium
Nitrogen	7							
Aluminum	13							
Chlorine	17							
Calcium	20							
Oxygen	8							

B. Ionic Compounds and Formulas

1. Physical properties

Compound	Appearance	Density	Melting Point
Sodium chloride, NaCl			

2. Formulas of ionic compounds

Name	Positive Ion	Negative Ion	Formula
Lithium iodide	Li^+	I^-	LiI
Aluminum oxide			
Calcium sulfide			
Magnesium bromide			
Potassium nitride			
Sodium fluoride			

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3. Names of ionic compounds

Formula	Positive Ion	Negative Ion	Name
K_2S	K^+	S^{2-}	Potassium sulfide
BaF_2			
MgO			
Na_3N			
$AlCl_3$			
Mg_3P_2			

C. Metals in Ionic Compounds with Variable Charge

1. Physical properties

Compound	Appearance	Density	Melting Point
Iron(III) chloride, $FeCl_3$			

2. Formulas of ionic compounds

Name	Positive Ion	Negative Ion	Formula
Iron(III) chloride	Fe^{3+}	Cl^-	$FeCl_3$
Iron(II) oxide			
Copper(I) sulfide			
Copper(II) nitride			
Zinc oxide			
Silver sulfide			

3. Names of ionic compounds

Formula	Positive ion	Negative ion	Name
Cu_2S	Cu^+	S^{2-}	Copper(I) sulfide
Fe_2O_3			
$CuCl_2$			
FeS			
Ag_2O			
$FeBr_2$			

D. Ionic Compounds with Polyatomic Ions

1. Physical properties

Compound	Appearance	Density	Melting Point
K_2CO_3			

2. Formulas of ionic compounds

Name	Positive Ion	Negative Ion	Formula
Potassium carbonate	K^+	CO_3^{2-}	K_2CO_3
Sodium nitrate			
Calcium bicarbonate			
Chromium (III) hydroxide			
Lithium phosphate			
Potassium sulfate			

3. Names of ionic compounds

Formula	Positive ion	Negative ion	Name
$CaSO_4$	Ca^{2+}	SO_4^{2-}	Calcium sulfate
$Al(NO_3)_3$			
Na_2CO_3			
$MgSO_3$			
$Cu(OH)_2$			
$Mg_3(PO_4)_2$			

E. Molecular Compounds

1. Physical properties

Compound	Appearance	Density	Melting Point
Water, H_2O			

2. Formulas of molecular compounds

Name	Formula	Name	Formula
Dinitrogen pentoxide		Dinitrogen trisulfide	
Silicon tetrachloride		Oxygen difluoride	
Phosphorus tribromide		Iodine heptafluoride	

3. Names of molecular compounds

Formula	Name	Formula	Name
ClF_5		SF_6	
CS_2		N_2O_3	
PCl_5		SeF_6	

F. Electron-Dot Formulas and Shape

Formula	1. Electron- Dot Formula	2. Number of Electron Groups	3. Electron-Group Arrangement	4. Number of Bonded Atoms	5. Shape	6. Polar or Nonpolar?
H_2O						
SF_2						
NI_3						
$SiBr_4$						
SO_3						
CO_2						