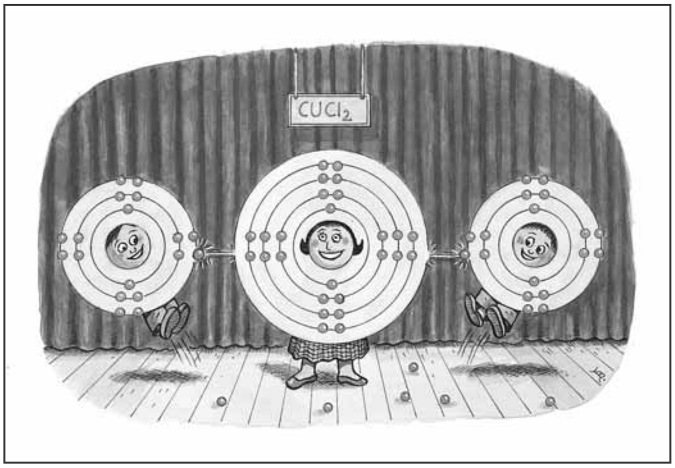
Active Chemistry The Periodic Table

Activity 8 How Atoms Interact with Each Other



GOALS

In this activity you will:

- Relate patterns in ionization energies of elements to patterns in electron arrangements.
- Use your knowledge of electron arrangements and valence electrons to predict formulas for compounds formed by two elements.
- Contrast ionic bonding and covalent bonding.
- Draw electron-dot diagrams for simple molecules with covalent bonding.

What Do You Think?

You have learned that the chemical behavior of an atom is determined by the arrangement of the atom's electrons, specifically the valence electrons. The salt that you put on your food is chemically referred to as NaCl—sodium chloride.

- How might the valence electrons of sodium (Na) and chlorine (Cl) interact to create this bond?

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

Investigate

1. In **Activity 3** you read that John Dalton assumed that chemical compounds formed from two elements combined in the simplest possible combination—one atom of each element. In **Activity 6** you began to see that an atom's chemical behavior reflects its excess or deficiency of electrons relative to an atom of the closest noble gas on the periodic table. Use the list of ionization energies in **Activity 6** to answer the following questions:

What Do You Think?

Student's responses will vary greatly depending on their backgrounds. We know that metals like sodium will lose an electron in order to achieve the stability of a noble gas electron configuration. On the other hand, chlorine is a nonmetal and has a tendency to gain one electron in order to achieve a noble gas electron configuration. Thus, we conclude that sodium will give its electron to the chlorine and the two elements can then combine ionically.

Student Conceptions

In this activity, students are led to see that electron arrangements are responsible for patterns in both ionization energies and chemical behavior. Patterns are noted by comparison to the noble-gas elements. The arguments are multi-stepped and students often have difficulty when required to make more than two logical steps in an argument. It is helpful to demonstrate a series of steps in an argument. For example, sodium has a small first ionization energy and a large second ionization energy. Its electron configuration ends in $3s^1$ and it is one electron away from neon, a noble gas. Since the noble gases are the most stable elements, it makes sense that it is relatively easy to remove sodium's first electron, but much more difficult to remove the second one. Therefore, the most stable electron arrangement for sodium is attained when it has one electron removed. So, when an atom of sodium makes a bond with an atom of another element, it seeks an element that will allow it to lose one electron. The element sodium bonds with must therefore seek to gain electrons. A similar series of steps may be demonstrated alongside these for chlorine. At the end of both series, the conclusion is that sodium and chlorine form a compound with a 1:1 ratio of atoms of each. In addition, for some reason, it is easier for most students to understand the concept of gaining electrons to form stable arrangements than losing them. This is perhaps tied to more comfort with increasing (adding) than decreasing (subtracting) on a number line. Therefore, some students find it easier to begin with an argument for chlorine before the argument for sodium.

a) Which atoms have the smallest values for first ionization energies? (Remember, the first ionization energy is the amount of energy required to remove the first electron.)

Where are these atoms located on the periodic table?

b) What do you observe about the amount of energy required to remove the second electron from atoms of the elements identified in (**a**) above?

c) Use your understanding of the arrangement of electrons in this group of elements to suggest a reason for the pattern you noted in (**b**).

d) Which atoms have the smallest values for second ionization energies? Where are these atoms located on the periodic table?

e) Use your understanding of the arrangement of electrons in this group of elements to suggest a reason for the pattern you noted in (**d**).

2. Once you recognize the role of an atom's electron arrangement—especially the valence electrons—in an atom's chemical activity, you can often predict formulas for compounds formed by two chemical elements. (Recall that valence electrons are the electrons located in the highest energy level, the levels designated by the sublevel having the highest numbers.)

Sodium (Na) has one valence electron in the 3*s* sublevel. By losing that electron, the sodium atom becomes a sodium ion and it has the same stable electron arrangement as neon. What is the electric charge on the resulting Na ion?

Consider a chlorine atom.

a) How many valence electrons does a chlorine atom have?

b) How many electrons does a chlorine atom need to gain to have the same number of electrons as an argon atom?

c) When a chlorine atom gains an electron, a chloride ion is formed. Since the original chlorine atom was electrically neutral and it gained a negative electron to form the ion, what is the electric charge (sign and value) on the resulting ion?

d) Each chlorine atom is capable of accepting one electron. Describe how you think the compound sodium chloride (NaCl) is formed?

3. Consider the reaction between aluminum and zinc chloride (similar to the reaction in **Activity 3**). The zinc atoms in zinc chloride have two valence electrons located in the 4*s* sublevel. You can note the two valence electrons in the electron arrangement marked on the periodic table.

In order to acquire the electron configuration of argon atoms a rather stable arrangement, the zinc atoms give up their two valence electrons to form zinc ions. Since the original zinc atom was electrically neutral and it lost two negative electrons to form the ion, the resulting ion has a positive charge with a magnitude two times the charge on the electron. It has a plus two charge.

Investigate

Teaching Suggestions and Sample Answers

Chem Tip:
The first part of this activity should flow very nicely. Expect some problems when you start talking about compounds like aluminum oxide. The question will probably come up about how we know whether the compound is ionic or covalent. At this point, explain to the students that most compounds that have atoms of the first two columns combining with the sixth and seventh columns are probably going to be ionic. The others we may need more information to know how to determine the character of the bond.

This is also a good time to show students that when we write the formula of a compound, we write the metal character or positive ion first. They should also be aware that the left side of the periodic table is classified as metals and that the right side is nonmetals. The metalloids are in the gray area between the two.

1. **a)** Alkali metals; 1st column. The last electron is always going into a new energy level and the *s* sublevel.

b) The alkali metal ions have a noble gas configuration. It will require an extremely large amount of energy to remove the 2nd electron from the alkali metal ion.

c) When the first electron is removed from the alkali metal, the remaining electrons are arranged in the lower-energy levels. The nucleus positive charge is able to pull the remaining electrons closer to the nucleus. This will require a greater amount of energy to remove the next electron.

d) Alkaline earth metals; 2nd column.

e) When alkaline earth elements lose an electron from their outermost energy level, they still have one electron remaining in the outermost energy level. They now have the configuration of an alkali metal. These ions want to lose one more electron to have the electron configuration of a noble gas.

2. **a)** 7 valence electrons.

b) Needs to gain 1 electron.

c) Cl^-; it has a negative charge.

d) Sodium donates one electron to the chlorine atom to form an ionic compound. It should be noted that we write the formula as NaCl, but we must remember that it is not a sharing of electrons.

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a) Each chlorine atom is capable of accepting one electron. How many chlorine atoms are needed to accept the 2 electrons that zinc atoms have to give?

b) When writing the formula for a compound, the number of atoms necessary to balance the loss and gain of electrons can be designated through the use of a subscript, such as the 2 in H_2O. How would you write the formula for the compound zinc chloride?

4. In a reaction between aluminum and zinc chloride, aluminum replaces the zinc in the zinc chloride, forming aluminum chloride and zinc.

a) Consider an atom of aluminum. How many valence electrons does an aluminum atom have?

b) How many electrons does an aluminum atom need to give up to reach the same chemical stability as a neon atom?

c) What are aluminum atoms called after they give up their valence electrons? What is their electric charge (sign and value)?

d) How many chlorine atoms are needed to accept the electrons given up by an aluminum atom?

e) How would you write the formula for the compound aluminum chloride?

Chem Talk

FORMING COMPOUNDS

The Octet Rule

In this activity, you explained the formation of the compounds that you investigated by how the electrons are transferred or shared between atoms. Some scientists explain these observations using the octet rule. The octet rule works well with the representative elements and is stated as follows: atoms tend to gain or lose electrons during chemical reactions so that the atoms have an outer shell configuration of 8 electrons. The exceptions to this are the transition elements. They can form compounds that do not have 8 electrons in their outer shell. For example, when chlorine, one of the **halogens** (Group 17), gains one electron it now has 8 electrons in its outermost *s* and *p* sublevels (octet of electrons). Also, you should note that the name of all of the compounds that you have studied always started with the name of the metal and then followed with the nonmetal part. The second thing that you should note is that all of these compounds are binary (meaning two parts). **Binary compounds** always end with the suffix *ide* (except for a few compounds with common names like water and ammonia).

Chem Words

halogens: group VIIA (17) on the periodic table consisting of fluorine, chlorine, bromine, iodine, and astatine.

binary compound: a compound, formed from the combining of two different elements.

ionic bond: the attraction between oppositely charged ions.

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

3. a) Two chlorine atoms are needed to accept the two electrons of zinc.

   b) $ZnCl_2$

4. a) 3 valence electrons.

   b) 3 electrons.

   c) Aluminum cation; + 3 (Al^{3+})

   d) Three chlorine atoms are needed to accept the three electrons. Remember, each chlorine atom can accept one electron.

   e) $AlCl_3$

Covalent and Ionic Bonds

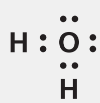
You may have noticed that the column headed by carbon in the periodic table has not received a lot of attention so far. In **Activity 7** you learned that atoms of these elements contain 4 valence electrons. Atoms with a small number of valence electrons give up electrons, and atoms with a large number of valence electrons gain additional electrons to have the same electron arrangement as an atom of the nearest noble gas. Except for helium, with 2 valence electrons, the noble gases each have 8 valence electrons. What do atoms of carbon do: give up their 4 valence electrons, or gain 4 more?

In actuality, atoms of carbon do neither. Instead of giving or taking electrons, carbon atoms share electrons with atoms of other elements. Instead of giving or taking electrons to form what are called **ionic bonds**, carbon atoms share electrons with atoms of other elements to form what are called **covalent bonds**. In fact, all nonmetallic elements whose atoms have four or more valence electrons can form covalent bonds by sharing electrons. This sharing results in a situation in which each atom is associated with 8 valence electrons, as is characteristic of an atom of a noble gas.

Covalent bonding can be illustrated using electron-dot diagrams, in which each valence electron is indicated by a dot (or other appropriate symbol) around the chemical symbol for the element in question. Consider the following covalent compound illustrations:

hydrogen chloride contains one hydrogen atom and one atom of chlorine:

water contains 2 hydrogen atoms and one oxygen atom:



and carbon dioxide contains one atom of carbon and 2 oxygen atoms:

You can count 8 electrons around the chlorine in hydrogen chloride (note that hydrogen can only have 2 electrons). In water the oxygen has 8 electrons around it and hydrogen again has only 2 electrons. Carbon dioxide shows that oxygen contains 8 electrons and carbon has 8 electrons as well. These shared electrons in these examples all produce stable covalent compounds.

Checking Up

1. When naming a binary compound, which element is named first, the metal or the nonmetal? Give an example to explain your answer.
2. Explain the difference between an ionic and a covalent bond.
3. Draw electron-dot diagrams showing covalent bonding in the following compounds:
   a) water (two atoms of hydrogen, one atom of oxygen). Note: Since the noble gas nearest hydrogen is helium, with only two valence electrons, hydrogen atoms need be associated with only two valence electrons.
   b) methane (four atoms of hydrogen, one atom of carbon).
   c) ammonia (three atoms of hydrogen, one atom of nitrogen).
   d) carbon tetrachloride (four atoms of chlorine, one atom of carbon).

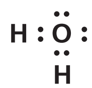
ChemTalk

Checking Up

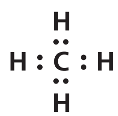
1. Metals are listed first in binary compounds. Examples are: sodium chloride, barium fluoride, calcium oxide, lithium bromide, and magnesium iodide.

2. A covalent bond is the sharing of electrons between the atoms. An ionic bond is non-sharing of electrons. The metal takes on the positive character and the nonmetal will have the negative character.

3. a)

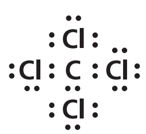


b)



c)

d)



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Reflecting on the Activity and the Challenge

In this activity you learned that atoms of two chemical elements will interact with each other in order to achieve a stable electron arrangement like that of nearby noble gases. The way in which atoms interact is based on their excess or deficiency of electrons relative to atoms of the closest noble gas on the periodic table. An atom's excess or deficiency of electrons relative to the closest noble gas is readily indicated by the position of an element on the periodic table. In this way the periodic table can be used to predict the chemical formulas when two elements interact to form a compound. This information can be deduced from the periodic table. Perhaps you can invent a way to make this more explicit as you create your periodic table game. How might you incorporate this information into your game to meet the **Chapter Challenge?**

Chemistry to Go

1. From the periodic table on the back inside cover, identify the excess or deficiency of electrons in an atom of each of the following pairs of elements relative to an atom of the closest noble gas, and then predict the formula of the compound formed when these elements interact:

   a) sodium and oxygen (to form sodium oxide),

   b) magnesium and chlorine (to form magnesium chloride),

   c) aluminum and oxygen (to form aluminum oxide).

2. a) In your *Active Chemistry* log, draw a simplified periodic table that contains only the first three rows of the periodic table. Your table should have 3 rows and 8 columns, and should contain the elements with atomic numbers 1 through 18.

   b) In the box for each element, write the symbol for the element.

   c) In the columns headed by lithium, beryllium, and boron, indicate the charge (sign and value) of the ion formed when atoms of these elements give up electrons to attain a more stable electron arrangement.

   d) In the columns headed by nitrogen, oxygen, and fluorine, indicate how many electrons are gained by atoms of those elements to attain a more stable electron arrangement.

3. You know the formula for sodium chloride (NaCl) and from this knowledge you can also write the formula for potassium chloride, cesium bromide, lithium iodide and sodium fluoride.

Chemistry to Go

1. a) Sodium and oxygen (to form sodium oxide)

   Sodium will release 1 electron and oxygen will accept two electrons. Na_2O

   b) Magnesium and chlorine (to form magnesium chloride)

   Magnesium will release 2 electrons and each chlorine will accept one electron. $MgCl_2$

   c) Aluminum and oxygen (to form aluminum oxide)

   Aluminum will release 3 electrons and oxygen will accept two electrons. The common number of electrons that must be shared is 6 electrons. Then you will need 2 aluminum and 3 oxygen atoms. Al_2O_3

2. a–d)

IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
H +1							He
Li +1	Be +2	B +3	C	N −3	O −2	F −1	Ne
Na +1	Mg +2	Al +3	Si	P −3	S −2	Cl −1	Ar

a) What tool makes it possible for you to do this, even though you may have never investigated these compounds?

b) Using the periodic table, explain what information you used to help explain how you arrived at the formulas.

4. The formula for calcium chloride is $CaCl_2$ and from this knowledge you should be able to write the formulas of the alkaline earth metals (Group 2) and halogens combining.

a) Write the formula for magnesium bromide, strontium iodide, beryllium fluoride, barium chloride and calcium iodide.

b) What information from the periodic table did you use to support your writing the formulas of these compounds?

5. A compound that was used previously is aluminum chloride ($AlCl_3$). Use your understanding of why elements are grouped together and are called a family, to write the formula for each of the following compounds:

a) boron fluoride, b) aluminum bromide,
c) gallium iodide, d) indium (III) chloride,
e) thallium (III) bromide.

6. You have explored how the alkali, alkaline earth metals, and IIIA group (boron, aluminum, gallium, indium, and thallium) combine with the halogens, but how do these metals combine with the group VIA elements (oxygen, sulfur, selenium, tellurium, and polonium)? Look at a few compounds such as sodium oxide that has a formula of Na_2O. Alkali metals like sodium "want" to lose one electron. Oxygen "wants" to gain 2 electrons. Therefore, when the alkali metals combine with oxygen or other elements of group VIA, they should have a similar formula.

a) Write the formula for each of the following compounds:

i) potassium sulfide ii) rubidium selenide
iii) lithium telluride iv) sodium sulfide
v) cesium oxide

You can do the same thing with the alkaline earth metals combining with the group VIA elements. Calcium oxide has the formula CaO. The alkaline earth metals want to lose 2 electrons and the group VIA elements want to gain 2 electrons. They will combine in a 1:1 ratio.

b) Write the formula for each of the following compounds:

i) magnesium sulfide ii) strontium selenide
iii) barium oxide iv) beryllium telluride
v) calcium sulfide

3. **a)** The periodic table is the tool that makes this possible.

b) We know that all of the alkali metals have one electron in the outer *s* sublevel and they all want to give up one electron. We also know that the halogens want to gain one electron. Therefore, the general formula for alkali metals combining with halogens is MX, where M represents the metal and X represents the nonmetal or in this case halide. Then we conclude the formulas are: KCl, CsBr, LiI, and NaF.

4. **a)** The formulas are: $MgBr_2$, SrI_2, BeF_2, $BaCl_2$, CaI_2.

b) We note that all of the alkaline earth metals have 2 electrons in the outermost *s* sublevel and they want to give up two electrons. The halogens we know want to accept one electron and therefore, it will require two halogens to combine with an alkaline earth metal. The general formula for alkaline earth metals with halogens is: MX_2, where M represents the metal character and X the nonmetal character.

5. The group IIIA elements have 3 valence electrons in their outermost *s* and *p* sublevels. Then in combining with the halogens we could write the general formula as MX_3. Then the correct formulas are:

a) BF_3, **b)** $AlBr_3$, **c)** GaI_3, **d)** $InCl_3$, **e)** $TlBr_3$.

6. (This problem is designed to help students understand how we use the electron configuration and valence electrons to determine the correct formulas.)

a) The general formula for the group IA combining with group VIA is M_2X

i) potassium sulfide, K_2S
ii) rubidium selenide, Rb_2Se
iii) lithium telluride, Li_2Te
iv) sodium sulfide, Na_2S
v) cesium oxide, Cs_2O

b) The general formula for the group IIA combining with group VIA is MX

i) magnesium sulfide, MgS
ii) strontium selenide, SrSe
iii) barium oxide, BaO
iv) beryllium telluride, BeTe
v) calcium sulfide, CaS

c) The general formula for the group IIIA combining with group VIA is M_2X_3

i) boron sulfide, B_2S_3
ii) aluminum selenide, Al_2Se_3
iii) gallium telluride, Ga_2Te_3
iv) indium oxide, In_2O_3
v) thallium sulfide, Tl_2S_3

Magnification of sulfur crystal

Finally, look at the group IIIA elements combining with the group VIA elements. Aluminum oxide has the formula Al_2O_3. The group IIIA elements want to lose 3 electrons and the group VIA elements want to gain 2 electrons. In order to make a whole number exchange 6 electrons must be transferred. (Remember to make sure that your formula has the correct number of electrons being transferred.)

c) Write the formula for the following compounds:

i) boron sulfide
ii) aluminum selenide
iii) gallium telluride
iv) indium (III) oxide
v) thallium (III) sulfide

Inquiring Further

Creating compounds with "inert" gases

For a long period of time the noble gases were called the inert elements, because it was assumed that they were non-reactive and did not want to gain or lose electrons. Research to find out if compounds can be formed with the noble gases. Record your finding in your *Active Chemistry* log. If time permits, share your findings with the class.

Inquiring Further

Creating compounds with "inert" gases

Of the noble gases, krypton, xenon, and radon appear to be the most common noble gases that seem to have successful chemical reactions. Compounds such as xenon difluoride (XeF_2), xenon tetrafluoride (XeF_4), and xenon hexafluoride (XeF_6) have been prepared. Other elements that have been found to combine with the noble gases are oxygen, chlorine, and nitrogen. Radon is radioactive and studies are limited on any compounds formed. The fluoride of this compound has been isolated.