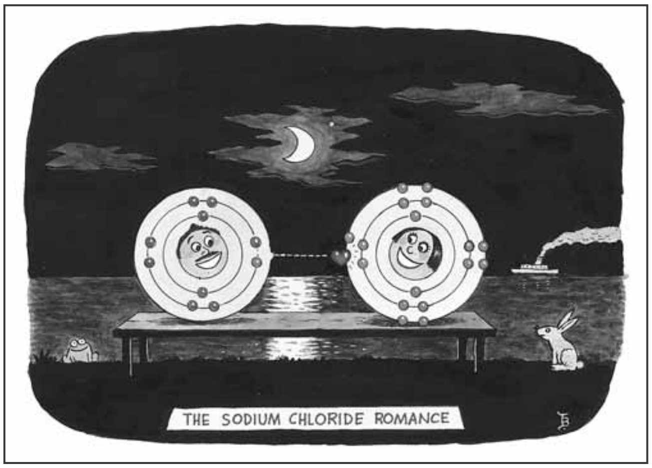
Active Chemistry The Periodic Table

Activity 7 How Electrons Determine Chemical Behavior



GOALS

In this activity you will:

- Investigate more patterns in the electron arrangements of atoms.
- Relate the positions of elements on the periodic table, their electron arrangements, and their distances from the nearest noble gas, to chemical properties of the elements.
- Relate electron arrangements to ionization energies.
- Assign valence numbers to elements and organize the periodic table according to valence numbers.

What Do You Think?

You have learned that electron configurations determine an atom's chemical behavior. You have also learned how these electrons are labeled according to a series of energy sublevels.

- How does the arrangement of electrons in an atom determine its chemical behavior?

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 6** you learned that elements with relatively high ionization energies have stable arrangements of electrons. One particular group of elements, located in the column at the extreme right of the table, exhibit high ionization energies and therefore have stable arrangements of electrons. They are called the noble gases.

What Do You Think?

The chemistry of an element is the behavior of its electrons. Electron arrangement is associated with families of elements. For example, we find that all of the alkali metals have an electron configuration that ends with an s^1. Then if we add sodium metal to water, we find that the reaction is very active and it produces hydrogen gas, a basic solution, and heat is released. The overall reaction is:

$2\ Na(s) + 2\ HOH \longrightarrow H_2(g) + 2NaOH(aq)$ + energy.

Or, we could speak in general terms and say that any alkali metal will behave in similar manner:

$2\ M(s) + 2\ HOH \longrightarrow H_2(g) + 2\ MOH(aq)$ + energy, where M is any alkali metal.

We could do the same type of investigation with the alkaline earth metals. So, in general, we can state that if we know the electron configuration of the family and how one of the elements of the family behaves in a particular reaction, we can then predict how the other elements of the family will react.

Students may have a basic understanding of how electrons are involved in bonding. The chemistry of the elements is the behavior of their electrons. The outermost, or valence electrons are responsible for the reactivity of the different elements. Elements are placed into families or groups in the periodic table according to their similar chemical behavior, which is based on their electron configurations.

Student Conceptions

Analyzing trends in electron arrangements provides students with an opportunity to concentrate on details and reason clearly. Difficulties arise when students are careless or cannot focus. Occasionally, students have trouble identifying the number of valence electrons. They either forget to include the *s* electrons, or they insist on counting all the electrons in the period, including the *d* electrons. In fact, the concept of valence number is somewhat misleading because *d* orbitals can be hybridized to make expanded valences (as touched upon in the **Inquiring Further** section). To work with the simpler rule, however, it is easiest to focus on a definition where the valence electrons are those assigned to the outermost *s* and *p* subshells of an element's configuration.

Look at the periodic table on the inside back cover for the assignment of electrons to energy sublevels for atoms of each of these elements. Focus on the sublevel at the end of the electron arrangement where the last electron is assigned.

a) Make and complete a chart like the one below in your *Active Chemistry* log. An example has been provided for you.

	Column A	**Column B**	**Column C**	**Column D**
Element	Energy level (number) to which the last electron is assigned	Sublevel (letter) to which the last electron is assigned	Number of electrons in the sublevel to which the last electron is assigned	Total number of all electrons of the energy level in Column A
Helium				
Neon				
Argon	*3*	*p*	*6*	*8*
Krypton				
Xenon				
Radon				

b) Look at the numbers in Column A in your chart. How are these numbers related to the respective rows of the periodic table in which each of the elements is located?

c) What pattern do you notice in Columns B and C?

d) What pattern do you notice in Column D?

2. The chemical behavior of an element can be understood by looking at the electron assignment of an atom of the element as compared to the electron assignments of neighboring noble gas atoms. The chemical inactivity of noble gas atoms reflects the stable arrangement of their electrons, one which other atoms cannot easily disturb. In the following questions you will compare the electron assignments in atoms with those of noble gases.

   a) Make and complete a chart like the following one in your *Active Chemistry* log. In this chart you will compare the electron assignments of lithium, beryllium, and boron to the electron assignment of helium ($1s^2$), the closest noble gas. An example has been provided for you.

Investigate

Teaching Suggestions and Sample Answers

1.

	Column A	Column B	Column C	Column D
Element	Energy level (number) to which the last electron is assigned	Sublevel (letter) to which the last electron is assigned	Number of electrons in the sublevel to which the last electron is assigned	Total number of all electrons of the energy level in Column A
Helium	1	*s*	2	2
Neon	2	*p*	6	8
Argon	3	*p*	6	8
Krypton	4	*p*	6	8
Xenon	5	*p*	6	8
Radon	6	*p*	6	8

b) Column A shows the energy level or period that the last electron is assigned.

c) Column B identifies the last sublevel and Column C lists the number of electrons occupying this sublevel.

d) Column D counts the number of electrons contained in all of the sublevels that are occupied in the energy level.

Active Chemistry The Periodic Table

Element being compared	Number of electrons more than those found in closest noble gas (He)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Lithium	*1*	*2*	*s*	*Row 2*	*Column 1*
Beryllium					
Boron					

b) Make and complete another chart like the one above in your *Active Chemistry* log. This time you will compare the electron assignments of sodium, magnesium, and aluminum to the electron assignment of neon ($1s^22s^22p^6$), the closest noble gas.

Element being compared	Number of electrons more than those found in closest noble gas (Ne)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Sodium					
Magnesium					
Aluminum					

c) Describe any patterns you notice in the charts in 2(a) and/or 2(b) above.

d) Make and complete a chart like the one at the top of the next page in your *Active Chemistry* log. In this chart you will compare the electron assignments of nitrogen, oxygen, and fluorine to the electron assignment of neon ($1s^22s^22p^6$), the closest noble gas. An example has been provided for you.

e) Make and complete another chart like the one at the top of the next page in your *Active Chemistry* log. This time you will compare the electron assignments of phosphorus, sulfur, and chlorine to the electron assignment of argon ($1s^22s^22p^63s^23p^6$), the closest noble gas.

2.

Element being compared	Number of electrons more than those found in closest noble gas (He)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Lithium	1	2	*s*	Row 2	Column 1
Beryllium	2	2	*s*	Row 2	Column 2
Boron	3	2	*p*	Row 2	Column 3

b)

Element being compared	Number of electrons more than those found in closest noble gas (Ne)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Sodium	1	3	*s*	Row 3	Column 1
Magnesium	2	3	*s*	Row 3	Column 2
Aluminum	3	3	*p*	Row 3	Column 3

c) Everything is the same except you are now in the 3rd period level or 3rd energy level instead of the 2nd energy level.

Element being compared	Number of electrons more than those found in closest noble gas (Ne)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Nitrogen	*3*	*2*	*p*	*Row 2*	*Column 5*
Oxygen					
Fluorine					

Element being compared	Number of electrons more than those found in closest noble gas (Ar)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Phosphorus					
Sulfur					
Chlorine					

f) Describe any patterns you notice in the charts 2 (d) and/or 2(e) above.

3. 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.

a) Write the symbol for each element in each appropriate box.

b) In the columns headed by lithium, beryllium, and boron, indicate how many more electrons are found in atoms of those elements than in an atom of the nearest noble gas. Place a plus sign in front of these numbers to indicate that these elements contain more electrons than their nearest noble gas element.

c) In the columns headed by nitrogen, oxygen, and fluorine, indicate how many fewer electrons are found in atoms of those elements than in an atom of the nearest noble gas. Place a minus sign in front of these numbers to indicate that these elements contain fewer electrons than their nearest noble gas element.

d) The carbon column was not listed in the table. How many fewer electrons are found in atoms of these elements than in an atom of the nearest noble gas? How many more electrons are found in atoms of these elements than in an atom of the last noble gas? What can you conclude about the position of the carbon column in respect to the other columns that you have examined?

d)

Element being compared	Number of electrons more than those found in closest noble gas (Ne)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Nitrogen	3	2	*p*	Row 2	Column 5
Oxygen	2	2	*p*	Row 2	Column 6
Fluorine	1	2	*p*	Row 2	Column 7

e)

Element being compared	Number of electrons more than those found in closest noble gas (Ar)	Energy level (number) to which the last electron is assigned	Energy sublevel (letter) to which the last electron is assigned	Location of element (row) in the periodic table	Location of element (column) in the periodic table
Phosphorus	3	3	*p*	Row 3	Column 5
Sulfur	2	3	*p*	Row 3	Column 6
Chlorine	1	3	*p*	Row 3	Column 7

f) Everything is the same except they are in row 3 or 3rd period energy level.

3.

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

Chem Tip:
Hydrogen should not have +1 at this time according to the directions. However, hydrogen is a unique element and should not really be placed in the column with the alkali metals nor should it be placed with the halogens. Some periodic tables show it standing by itself. It usually has the charge of plus one in compounds and especially in acids. If it is acting as a nonmetal such as sodium hydride, then it will have a –1 charge. Since the majority of the compounds find hydrogen in the +1 state we will place it above the alkali metals.

4. The questions in **Step 2** asked you to compare the electron assignments in atoms of the second and third rows with the electron assignments of the noble gas that was closest in atomic number to those elements. You noted that electrons are added to the *s* and *p* sublevels of the energy level whose number is the same as the row of the periodic table the elements are found in. For instance, lithium has one more electron than its closest noble gas element. That additional electron is added to the *s* sublevel of the second energy level, corresponding to the second row, where lithium is located.

   The number of an electron energy level is significant, because the higher the number, the greater the average distance between the nucleus and the electron. The electrons in the energy levels with the highest number are, on average, the farthest from the nucleus. Because differences in electrons located in the outermost level distinguish an atom from its nearest noble gas, these are the electrons responsible for the atom's chemical behavior. These electrons are often called valence electrons. The general definition of valence electrons are those electrons found in the outermost energy level *s* and *p* orbitals. The maximum number of valence electrons that you can have is 8 for the representative elements (2 in the *s* and 6 in *p* sublevel). For example, sodium contains one valence electron since its outermost level is 3 and sublevel is *s*. It does not have any electrons in the *p* sublevel. Bromine would have seven valence electrons, since its outermost energy level is 4 and it contains 2 electrons in *s* sublevel and 5 electrons in *p* sublevel. Use the assignment of electrons to energy sublevels in the periodic table on the inside back cover and your answers to the questions in **Steps 1** and **2** to answer the following questions:

   a) How many valence electrons are in an atom of helium? Neon? Argon? Krypton? Xenon? Radon?

   b) How many valence electrons are in an atom of lithium? Sodium? Potassium? Rubidium? Cesium? This family of elements is known as the alkali metals.

   c) How many valence electrons are in an atom of beryllium? Magnesium? Calcium? Strontium? Barium? This family of elements is known as the alkaline earth metals.

   d) How many valence electrons are in an atom of boron? Aluminum?

   e) How many valence electrons are in an atom of carbon? Silicon?

   f) How many valence electrons are in an atom of nitrogen? Phosphorus?

   g) How many valence electrons are in an atom of oxygen? Sulfur?

   h) How many valence electrons are in an atom of fluorine? Chlorine? Bromine? Iodine? This family of elements is known as the halogens.

Chem Tip:
Notice that the Roman numerals used for each column correspond to the number of valence electrons contained in the atoms. The alkali metals have one valence electron and so we call this Column IA. The noble gases have 8 valence electrons (with the exception of helium, which only has 2 valence electrons) and they are headed by column VIIIA.

4. **a)** Helium has 2 valence electrons and the other noble gases have 8 valence electrons.

b) 1 valence electron

c) 2 valence electrons

d) 3 valence electrons

e) 4 valence electrons

f) 5 valence electrons

g) 6 valence electrons

h) 7 valence electrons

Chem Talk

THE NOBLE GASES

The Discovery of Argon

Imagine that you prepared two samples of nitrogen, each one liter in volume, and found one to have a mass of 1.250 g (grams) and the other a mass of 1.257 g. You might be tempted to attribute the difference to experimental error. Lord Rayleigh didn't! In 1892 he decomposed ammonia to generate one liter of nitrogen with a mass of 1.250 g. In another preparation method, he isolated one liter of nitrogen with a mass of 1.257 g by removing what he thought were all the other gases from a sample of air.

What accounted for the difference in masses of the two liter samples? Could there be yet another gas in the air that Rayleigh didn't know about? William Ramsay, a colleague of Rayleigh, looked to the experiments conducted by Henry Cavendish a hundred years earlier. Henry Cavendish (the discoverer of hydrogen) had been puzzled by a small bubble of gas remaining after he had chemically absorbed all of a sample of nitrogen he had similarly extracted from the atmosphere.

As Cavendish had done, Ramsay extracted a sample of nitrogen from the atmosphere and then chemically absorbed all of the nitrogen in that sample. He looked at the spectrum of the remaining bubble of gas, just as you have looked at the spectra of various gases in **Activity 4** and **5**. The new spectral lines of color he saw showed him that the bubble of gas was a new element, which today we know as argon. It had previously escaped notice because of its rarity and lack of chemical activity.

A New Family

When Mendeleev formulated the first periodic table argon had not been discovered, and therefore it had not been placed in the periodic table. There was no obvious place for argon. A new column was created. A prediction was therefore made that there would be other elements with similar properties to argon. The other elements of this family (He, Ne, Kr) were subsequently discovered by the end of the 19th century.

Checking Up

1. Why did one liter of nitrogen prepared by Lord Rayleigh appear to have a greater mass than the other liter prepared by a different method?
2. What are two reasons that the noble gases had escaped notice?

ChemTalk

Checking Up

1. The one liter of nitrogen gas collected by Lord Rayleigh not only contained nitrogen gas but also contained a small amount of argon gas as well.

2. The noble gases are rare and they are basically unreactive with other elements. Since they do not react with other chemicals, except in special circumstances, they are often called the inert gases.

Chem Tip:
The periodic table that is on the inside back cover of the Student Book shows that one of the ways we can count the columns is to start with 1 and count over to 18 (which is the noble gases). We see that with this system the transition metals are columns 3 through 12. The periodic table hanging on your wall may have a different counting system, but it should be easy to figure out how they are counting the columns.

Active Chemistry The Periodic Table

Chem Words

noble gas (also rare or inert gas): a family of elements (Group 18 or VIIIA) of the periodic table

Unlike atoms of the other chemical elements, atoms of elements in this column are so stable that they either do not react at all, or they react only in unusual circumstances, with other elements. For this reason, this family has been known as **rare** gases (because they are rare in abundance), **inert** gases (because they are not chemically reactive), or **noble** gases.

Reflecting on the Activity and the Challenge

In this activity you have learned that the electrons in the energy sublevels with the highest number are, on the average, the farthest from the nucleus of an atom. These electrons, also known as valence electrons, determine the atom's chemical behavior. This chemical behavior is best understood in relationship to the arrangement of electrons in energy sublevels in atoms of noble gases, which, by virtue of their chemical inactivity, have a stability which is unmatched by other chemical elements. The key is an atom's excess or deficiency of electrons compared to an atom of the nearest noble gas on the periodic table. This excess or deficiency is readily indicated by the position of an element on the periodic table. How will you include this in your game about the periodic table?

Chemistry to Go

1. From the periodic table on the back inside cover, identify the excess or deficiency of electrons in an atom of a given element relative to an atom of the closest noble gas. Be sure to indicate both the number of electrons and a sign (plus or minus) to indicate whether the electrons are in excess or deficiency.

   a) calcium
   b) arsenic
   c) potassium
   d) iodine

2. Listed below are groups of three elements. For each group determine which two elements have more in common in terms of electron arrangement and therefore exhibit more similar chemical behavior. Give a reason for your selection.

   a) carbon, nitrogen, silicon
   b) fluorine, chlorine, neon
   c) sulfur, bromine, oxygen
   d) sodium, magnesium, sulfur
   e) helium, neon, hydrogen

Chemistry to Go

1. a) Calcium + 2. Calcium has 20 electrons and it would like to lose 2 electrons to have the noble gas configuration of argon with the $3d^{10}$ electrons as well. This is a metal characteristic property in wanting to lose electrons.

   b) Arsenic − 3. Arsenic could gain 3 electrons and have the same configuration as krypton. Arsenic is unique in that it can also play the role of a metal and lose all 5 valence electrons and have the configuration of argon with the $3d^{10}$ electrons as well. At this time, stay with the students choice of − 3.

   c) Potassium + 1. Potassium wants to lose an electron and have the configuration of argon.

   d) Iodine − 1. Iodine is acting as a nonmetal and wants to gain one electron, so that its configuration is xenon.

2. a) Carbon and silicon (4 valence electrons). Nitrogen has 5 valence electrons.

   b) Fluorine and chlorine (7 valence electrons). Neon is a noble gas and has 8 valence electrons.

   c) Sulfur and oxygen (6 valence electrons). Bromine has 7 valence electrons.

   d) Sodium and magnesium both are metals and they want to lose electrons. Sodium will lose 1 electron and magnesium will lose 2 electrons. Sulfur is a nonmetal and wants to gain 2 electrons.

   e) Helium and neon both are noble gases and have 2 and 8 valence electrons, respectively. Hydrogen has 1 valence electron.

3. a) Helium is a noble gas configuration and also has a high ionization energy, which implies that it is very stable. On the other hand, lithium has a low ionization energy and this implies that it wants to lose this electron to achieve the noble gas configuration of the stable helium atom.

   b) They are both metals and would like to lose electron(s) to achieve noble gas configuration of helium. However, beryllium is more stable because it requires more ionization energy to remove an electron from it as compared to lithium.

   c) Chlorine is more stable than magnesium based on the ionization energy. Magnesium wants to lose electrons and chlorine wants to gain electrons, but ionization energy is the best reason to use for stability.

   d) The noble gas argon is very stable as indicated by its ionization energy. Magnesium has a low ionization energy and it wants to lose electrons to become more stable, like neon.

   e) Neon is more stable than krypton based on the ionization energies of both. As you go down a column the ionization energy decreases.

3. Listed below are pairs of elements. For each pair determine which of the two has the most stable arrangement of electrons. You may refer to the table of first ionization energies in **Activity 6** and the periodic table on the back inside cover. Provide a statement explaining your choice in terms of ionization energy and electron arrangement.
   a) helium and lithium
   b) lithium and beryllium
   c) magnesium and chlorine
   d) magnesium and argon
   e) neon and krypton

4. a) Write the electron configuration for magnesium.
   b) Determine how many valence electrons magnesium contains.
   c) Write the electron configuration for barium.
   d) Determine how many valence electrons barium contains.
   e) How do the number of valence electrons of magnesium compare to the number of valence electrons of barium?
   f) What general statement can you make about the number of valence electrons of each element of the alkaline earth metals?

5. a) Write the electron configuration for cobalt.
   b) How many valence electrons does cobalt contain?

Inquiring Further

1. Valence electron of transition elements

How many valence electrons are there in an atom of iron (Fe, atomic number 26 and called a transition element)? When you look at the periodic table on the back inside cover, you see that iron has all the electrons in an atom of calcium plus six additional electrons in the 3*d* sublevel. Relative to the 2 electrons in the 4*s* sublevel in calcium, do these 3*d* electrons qualify as valence electrons? Explain your thinking. What can you say about the number of valence electrons in the other transition elements, from scandium to copper?

2. Ionization energies of beryllium (Be) atoms

The first three ionization energies of beryllium atoms are as follows:

1st = 1.49×10^{-18} J

2nd = 2.92×10^{-18} J

3rd = 2.47×10^{-17} J

Explain the magnitudes of the energies in terms of electron configurations and from this information determine how many valence electrons are contained in beryllium.

4. a) $1s^22s^22p^63s^2$

   b) 2 valence electrons (2 in the $3s^2$)

   c) $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^24d^{10}5p^66s^2$

   d) 2 valence electrons (2 in the $6s^2$)

   e) They are the same.

   f) They all have 2 valence electrons in the outermost sublevel. There are no electrons in the outermost *p* sublevel.

5. a) $1s^22s^22p^63s^23p^64s^23d^7$

   b) 2 valence electrons (cobalt's outermost energy level is 4 and it has 2 electrons in *s* sublevel). The 3*d* sublevel energy is fairly close to the 4*s* energy and so it is easy for an electron to leave the *d* sublevel. The common ionic states for cobalt are Co^{2+} and Co^{3+}.

Inquiring Further

1. Valence electron of transition elements

They have two valence electrons. The *d* electrons are inner-level electrons and can get involved in the chemistry of the atom. For example, copper can rearrange so that the *d* orbitals are filled and you have only one electron in the *s* orbital, but in general we say that they only have 2 valence electrons and realize that it can lose 1 electron from its *d* sublevel.

2. Ionization energies of beryllium (Be) atoms

The ground state of beryllium is: $1s^22s^2$

The first ionization of beryllium would give Be^+ and electron configuration is: $1s^22s^1$. General equation: $1s^22s^2$ + energy $\rightarrow 1s^22s^1 + e^-$ (Be^{+1})

Then the second ionization of beryllium will give Be^{2+} and electron configuration is: $1s^22s^0$. (Note that the second energy level is now empty and it has the configuration of helium.) General equation: $1s^22s^1$ + energy $\rightarrow 1s^2 + e^-$ (Be^{+2})

The third ionization of beryllium will give Be^{3+} and the electron configuration is: $1s^1$. General equation: $1s^2$ + energy $\rightarrow 1s^1 + e^-$ (Be^{+3})

The third ionization energy is extremely high because you are removing the electron from a noble gas configuration and you also have a charge on the nucleus of +4 that has a strong attraction for the remaining two electrons. The first and second ionization energies are less because you are removing electrons from the outer energy level and the main reason why the 2nd ionization energy is higher than the first is due to the attraction force of the nuclear charge — that they only have 2 valence electrons and realize that it can lose 1 electron from its *d* sublevel.