Electron Configuration and Periodic Properties | 7

LABORATORY GOALS

- Describe the color of a flame produced by an element.
- Use the color of a flame to identify an element.
- Write the electron configuration for an element.
- Plot a graph of atomic radius versus atomic number.
- Interpret the trends in atomic radii within a family and a period.

LAB INFORMATION

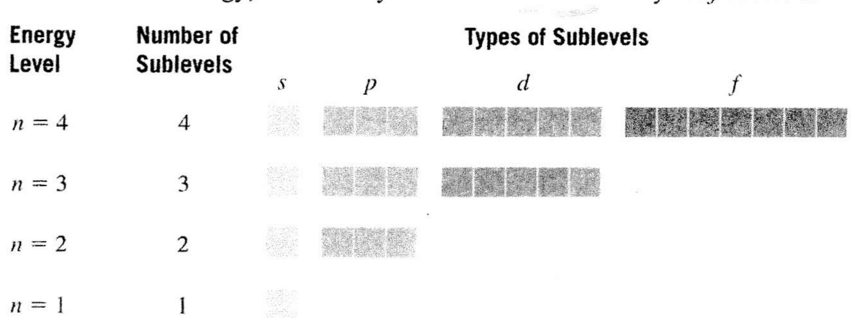
Time:	1½ h
Comments:	Obtain a periodic table or use the one on the inside cover of your textbook. Tear out the report sheets and place them beside the procedures.
Related Topics:	Electrons and protons, energy levels, and electron arrangement

CHEMICAL CONCEPTS

Electron Energy Levels

The chemical properties of an element strongly depends on the arrangement of the electrons. Every electron has a specific energy known as its *energy level* (n), starting with the lowest energy level $n = 1$ up to the much higher energy level $n = 7$. Electrons in the lower energy levels are usually closer to the nucleus, while electrons in the higher energy levels are farther away.

Each of the energy levels consists of one or more *sublevels*, in which electrons with identical energy are found. The sublevels are identified by the letters *s*, *p*, *d*, and *f* (see Figure 7.1). For example, the first energy level ($n = 1$) has one sublevel, 1*s*. The second energy level ($n = 2$) has two sublevels, 2*s* and 2*p*. The third energy level ($n = 3$) has three sublevels, 3*s*, 3*p*, and 3*d*. The fourth energy level ($n = 4$) has four sublevels: 4*s*, 4*p*, 4*d*, and 4*f*. Within each energy level, the *s* sublevel has the lowest energy, the *p* sublevel has the next lowest energy, followed by the *d* sublevel and finally the *f* sublevel.



▲ **FIGURE 7.1** The number of sublevels in an energy level is the same as the energy-level value of n.

A. Flame Tests

When electrons absorb specific amounts of energy, they can attain higher energy levels. When they drop to lower, more stable energy levels, energy is emitted. If the energy released corresponds to the energy of visible light, the emission produces a color that can be detected by the human eye. When heated, many of the elements in Groups 1A (1) and 2A (2) produce colorful flames. Each element produces a characteristic color.

B. Electron Configurations

In an *electron configuration*, electrons are arranged in orbitals starting with the sublevels that have the lowest energy. The number of electrons in each sublevel is written as a superscript.

Electron Configuration for Carbon

Type of orbital — Number of electrons

$1s^2 2s^2 2p^2$ Read as "one *s* two, two *s* two, two *p* two"

The electron arrangement of an element can be determined from its position in the periodic table. The electron configuration can be written by following the sublevel blocks across the periodic table, starting with period 1.

The ***s* block** is formed by Groups 1A (1) and 2A (2). The ***p* block** includes the elements in Groups 3A (13) to 8A (18). The period number gives the particular energy level of each *p* sublevel, beginning with 2*p* (see Figure 7.2).

Li $1s^2 2s^1$ **O** $1s^2 2s^2 2p^4$ **Ne** $1s^2 2s^2 2p^6$

Na $1s^2 2s^2 2p^6 3s^1$ **S** $1s^2 2s^2 2p^6 3s^2 3p^4$ **Ar** $1s^2 2s^2 2p^6 3s^2 3p^6$

On the periodic table, the 4*s* **block** fills next.

K $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$ **Ca** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

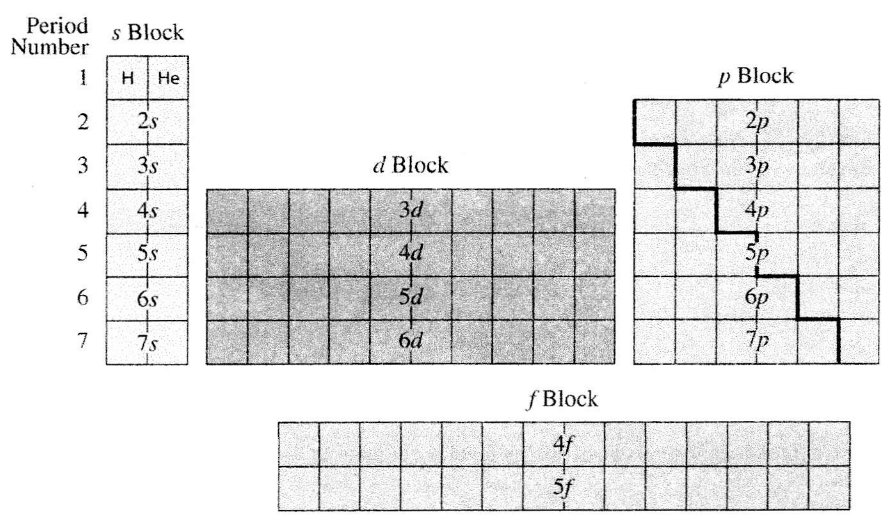
The ***d* block** begins with atomic number 21 and includes 10 transition metals. The energy level of each ***d* block** is one less than its period number.

Sc $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$ **Fe** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$ **Zn** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10}$

Ga $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^1$ **As** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$

Br $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ **Kr** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$

The ***f* block**, which has a maximum of 14 electrons, follows the 6*s* block. The energy level of each ***f* block** is two less than the corresponding period number.



▲ **FIGURE 7.2** Electron configuration follows the order of sublevels on the periodic table.

C. Atomic Radius

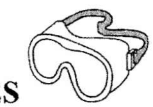
The size of an atom is determined by its atomic radius, which is the distance of the valence electrons from the nucleus. For each group of representative elements, the atomic size *increases* going from the top to the bottom because the outermost electrons in each energy level are farther from the nucleus. For example, in Group 1A (1), Li has a valence electron in energy level 2; Na has a valence electron in energy level 3; and K has a valence electron in energy level 4. This means that a K atom is larger than a Na atom, and a Na atom is larger than a Li atom.

The atomic radius of representative elements is affected by the attractive forces of the protons in the nucleus on the electrons in the outermost level. For the elements going across a period, the increase in the number of protons in the nucleus increases the positive charge of the nucleus. As a result, the electrons are pulled closer to the nucleus, which means that the atomic sizes of representative elements decreases going from left to right across a period.

Periodic Properties

The electron configurations of atoms are an important factor in the physical and chemical properties of the elements. Now we will look at properties of atoms, including the *valence electrons*, *atomic size*, *ionization energy*, and *metallic character*. Known as *periodic properties*, each type of property increases or decreases across a period, and then the trend is repeated again in each subsequent period.

In an electron configuration, the electrons in the highest, or outermost, energy level are called the *valence electrons*. The valence electrons determine the chemical properties of the elements. The *group numbers* of the representative elements give the number of valence electrons in elements of each group (vertical column). For example, all the elements in Group 1A (1) have one valence electron in an *s* orbital. All the elements in Group 2A (2) have two (2) valence electrons in an *s* orbital. Group 3A (13) has three valence electrons in *s* and *p* orbitals, Group 4A (14) has four valence electrons, Group 5A (15) has five valence electrons, Group 6A (18) has six valence electrons, halogens in Group 7A (17) have seven valence electrons, and Group 8 (18) (except for He) has eight valence electrons. The similarities of behavior occur periodically as the number of valence electrons is repeated.

EXPERIMENTAL PROCEDURES  *GOGGLES REQUIRED!*

A. Flame Tests

Materials: Bunsen burner, spot plate, flame-test (nichrome) wire, small graduated cylinder, 100-mL beaker, 1 M HCl, 0.1 M solutions (dropper bottles): $CaCl_2$, KCl, $BaCl_2$, $SrCl_2$, $CuCl_2$, NaCl, and unknown solutions

Obtain a spot plate and flame-test wire. Rinse the spot plate in distilled water.

Pour 10 mL of 1 M HCl into a 100-mL beaker. **CAUTION 1 M HCl is corrosive! Be careful when you use it. Wash off any HCl spills on the skin with tap water for 10 minutes.**

1. Place 6–8 drops of each test solution in separate indentations of the spot plate. Label the spot plate diagram in the laboratory report to match the types of solutions. Be careful not to mix the different solutions.

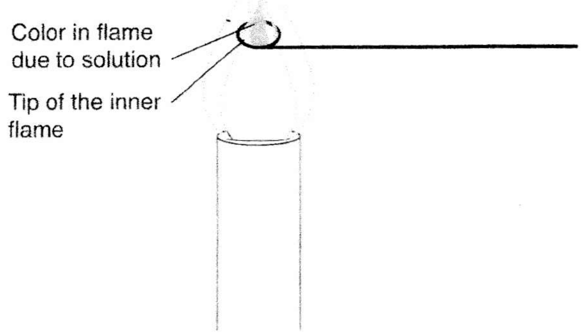
Adjust the flame of a Bunsen burner until it is nearly colorless with a blue inner cone. Clean the test wire by dipping the loop in the HCl in the beaker and placing it in the flame of the Bunsen burner. (If you see a strong color in the flame while heating the wire, dip it in the HCl again. Repeat until the color is gone.)

Observing Flame Colors

2. Dip the cleaned wire in one of the solutions on the spot plate. Make sure that a thin film of the solution adheres to the loop (see Figure 7.3). Move the loop of the wire to the tip of the inner blue flame. Record the color of each solution.

Clean the wire in HCl after each test. Repeat the flame test with the other solutions.

Note: The color of potassium in the KCl flame is short-lived. Be sure to observe the color of the flame from the KCl solution as soon as you put the wire in the flame.



▲ **FIGURE 7.3** Using a flame-test wire to test for flame color.

Identifying an Unknown Solution

Obtain one or more unknown solutions from your instructor and record their code letters.

3. Place 6–8 drops of each unknown solution in a clean spot plate. Repeat the flame-test procedure with each unknown solution and record the color of its flame.

4. From your list of colors for elements from step **2**, identify the element in each of the unknown solution.

You may wish to recheck the flame color of the known solution that best matches the flame color of an unknown. For example, if you think your unknown is KCl, recheck the color of the KCl solution to confirm.

B. Electron Configurations

1. Write the electron configuration of each atom listed on the laboratory report.
2. Indicate the number of valence electrons.
3. Determine the group number for each element.

C. Atomic Radius

The atomic radii for elements with atomic numbers 1–25 are listed in Table 7.1. On the graph, plot the atomic radius of each element versus the atomic number of that element. Be sure to connect all the points. Use the completed graph to answer questions in the report sheet.

TABLE 7.1 Atomic Radii for the Elements with Atomic Numbers 1–25

Element	Symbol	Atomic Number	Atomic Radius (pm*)
first period			
hydrogen	H	1	37
helium	He	2	50
second period			
lithium	Li	3	152
beryllium	Be	4	111
boron	B	5	88
carbon	C	6	77
nitrogen	N	7	70
oxygen	O	8	66
fluorine	F	9	64
neon	Ne	10	70
third period			
sodium	Na	11	186
magnesium	Mg	12	160
aluminum	Al	13	143
silicon	Si	14	117
phosphorus	P	15	110
sulfur	S	16	104
chlorine	Cl	17	99
argon	Ar	18	94
fourth period			
potassium	K	19	231
calcium	Ca	20	197
scandium	Sc	21	160
titanium	Ti	22	150
vanadium	V	23	135
chromium	Cr	24	125
manganese	Mn	25	125

*(picometer = 10^{-12} m)

Date ______________________ Name ______________________

Section ______________________ Team ______________________

Instructor ______________________ ______________________

Pre-Lab Study Questions | 7

1. Why does a sodium street lamp give off a yellow color, whereas a neon light gives off a red color?

2. Describe the energy levels of electrons in an atom.

3. Why do some elements produce colorful flames?

4. How can you identify an unknown element using a flame test?

5. Write the electron configuration for each of the following:

   a. lithium

   b. sodium

   c. potassium

6. Why do the electron configurations in Question **5** all end with the same sublevel notation?

Date ____________________ Name ____________________

Section ____________________ Team ____________________

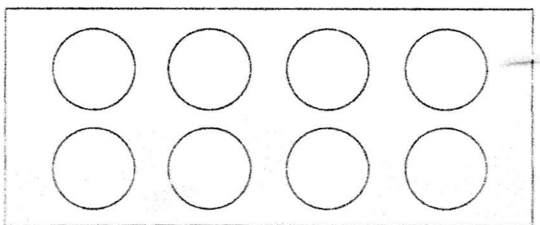
Instructor ____________________ ____________________

REPORT SHEET | LAB

Electron Configuration and Periodic Properties | 7

A. Flame Tests

1. Spot plate diagram



2.

Solution	Element	Color of Flame
$CaCl_2$	Ca	____________
KCl	K	____________
$BaCl_2$	Ba	____________
$SrCl_2$	Sr	____________
$CuCl_2$	Cu	____________
NaCl	Na	____________

3. Unknown Solution(s)
Identification letter ☐ ☐ ☐

Color of flame ____________ ____________ ____________

4. Element present ____________ ____________ ____________

Questions and Problems

Q1 You are cooking spaghetti in water you have salted with NaCl. You notice that when the water boils over, it causes the flame of the gas burner to turn bright orange. How would you explain the appearance of a color in the flame?

Date ______________________ Name ______________________

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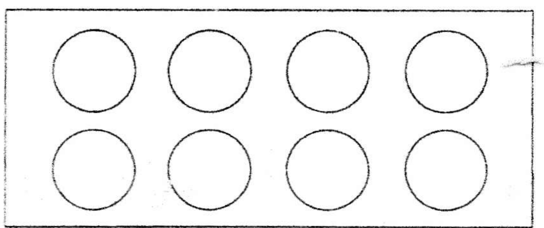
REPORT SHEET | LAB

Electron Configuration and Periodic Properties | 7

A. Flame Tests

1. Spot plate diagram



2.

Solution	Element	Color of Flame
$CaCl_2$	Ca	______________
KCl	K	______________
$BaCl_2$	Ba	______________
$SrCl_2$	Sr	______________
$CuCl_2$	Cu	______________
NaCl	Na	______________

3. Unknown Solution(s)
Identification letter ☐ ☐ ☐

Color of flame ______________ ______________ ______________

4. Element present ______________ ______________ ______________

Questions and Problems

Q1 You are cooking spaghetti in water you have salted with NaCl. You notice that when the water boils over, it causes the flame of the gas burner to turn bright orange. How would you explain the appearance of a color in the flame?

B. Electron Configurations

Atom	1. Electron Configuration	2. Number of Valence Electrons	3. Group Number
O			
Na			
Ca			
Fe			
Zn			
Br			
Sr			
Cd			
Xe			
Cs			
Pb			
Ra			

Questions and Problems

Q2 Complete the following:

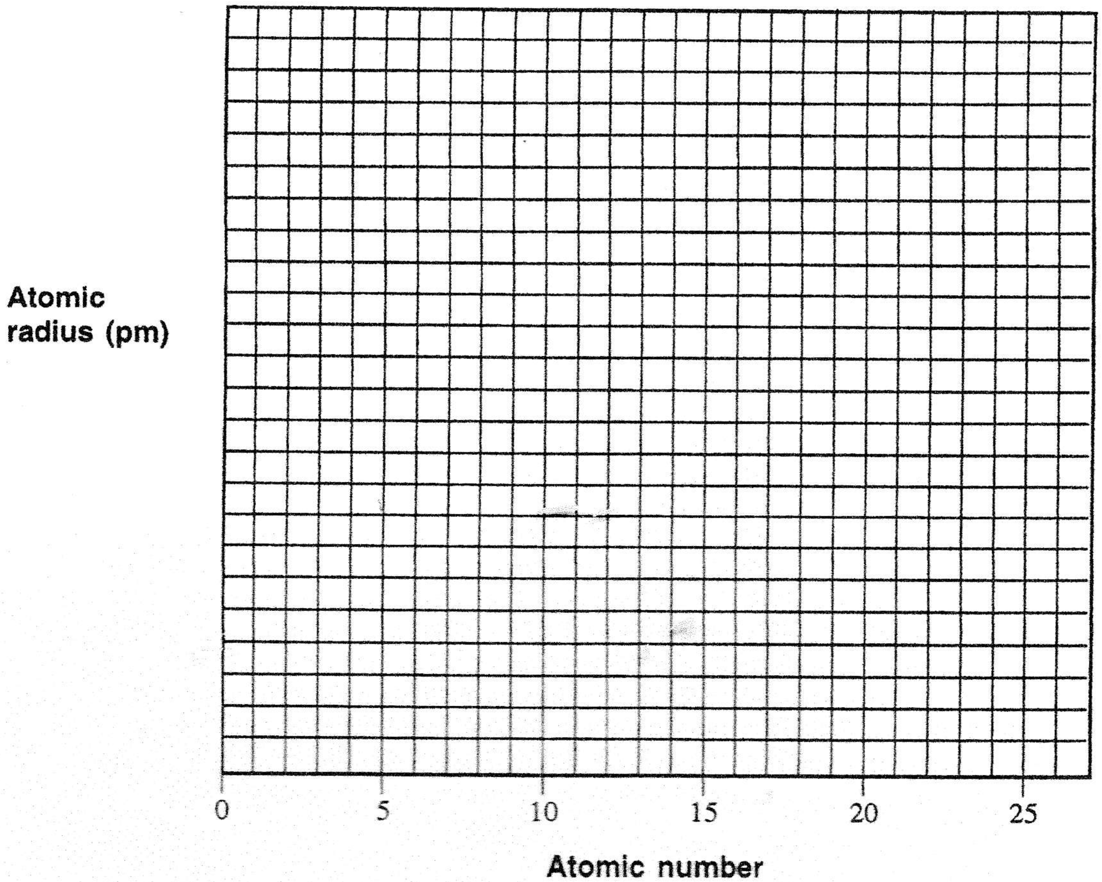
Number of sublevels in $n = 3$		Group number of carbon	
Number of orbitals in the $2p$ sublevel		Sublevel being filled by element with atomic number 47	
Maximum number of electrons in $3d$ sublevel		Sublevel that begins to fill after $4s^2$	
Maximum number of electrons in a $3p$ orbital		Number of valence electrons in As	

Q3 Give the symbol of the element described by each of the following:

First element that fills $3s$ sublevel		First element with five $3p$ electrons	
Period 4 element in the same group as F		$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$	
Element with $3d^6$		First element that completes $n = 3$	
Element with a half-filled $5p$ level		Period 6 element in the same group as Mg	

C. Atomic Radius

Atomic Radius vs. Atomic Number



Questions and Problems

Q4 Describe the change in the atomic radii for the elements in Period 2, from lithium to neon.

Q5 Why does the change for the atomic radii of the elements in Period 3 from sodium to argon look similar to Period 2?