ELECTRON CLOUDS AND PROBABILITY 5

5:1 QUANTUM NUMBERS

Einstein demonstrated that light not only has wave properties but also particle properties. DeBroglie reasoned that if light, which is considered a wave, has particle properties then particles of matter might show wave characteristics. Schrödinger expanded these concepts to describe electrons and to develop a theory called quantum mechanics or wave mechanics. **Quantum mechanics** allows us to determine the probability of finding an electron at a certain place in the atom. We do not know an electron's exact position. In fact, *it is impossible to know both the position and speed of an electron with absolute certainty*. This statement is the **Heisenberg Uncertainty Principle.**

Quantum mechanics uses four different **quantum numbers** to describe each electron in an atom. Three of the quantum numbers, n, l, and m, describe the atomic orbital. An **atomic orbital** is a region in space where there is a high probability of finding the electrons. The fourth quantum number, s, is used to designate a magnetic property of electrons called spin.

The **principal quantum number,** n, is used to describe the energy of the electron. The energy of an electron is determined by its average distance from the nucleus. The energy level in an atom is related to the radius of the electron cloud. The n quantum number can have values of 1, 2, 3, ... n. Each energy level, or quantum number, has n different sublevels. Each sublevel is described by the second quantum number l. The numerical values for l are the integers from 0 to $(n - 1)$. The l values are usually designated by letters, s for $l = 0$, p for $l = 1$, d for $l = 2$, and f for $l = 3$. All of the sublevels, except the s sublevel, have more than one orbital. Each orbital in a sublevel will have the same energy and usually the same shape as all the others in that sublevel.

The orbitals differ in their orientation in space around the nucleus. The third quantum number, m (magnetic quantum number), is used to describe each orbital within a sublevel. The values for m are integers from $-l$ to $+l$. For example, when $l = 1$, the sublevel is p. Since m can have any value from $+l$ to $-l$, its values are -1, 0, and $+1$. Thus there are three orbitals in the p sublevel, one located along each of the three perpendicular axes.

When an electron moves, it generates a magnetic field. The fourth quantum number, s, describes the direction of electron spin around its axis. There are two values permitted by the theory, $+1/2$ and $-1/2$. These values can be thought of as describing clockwise and counterclockwise electron rotation around its axis. According to the **Pauli Exclusion Principle** *no two electrons in an atom can have the same set of quantum numbers*. Thus, only two electrons, having opposite spins, can occupy an orbital. As a result, each sublevel can hold a maximum of twice as many electrons as the number of orbitals in the sublevel.

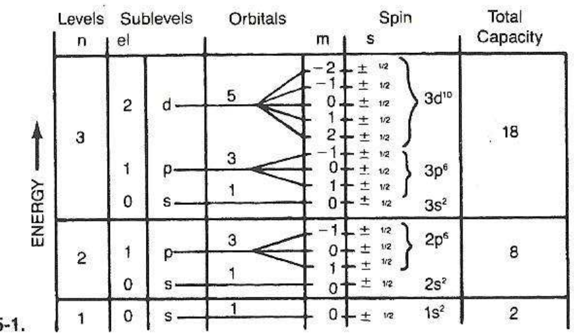


FIGURE 5-1.

PROBLEMS

1. Extend Figure 5-1 by showing the permitted values for each of the quantum numbers in the fourth energy level.
2. What is the maximum number of electrons that can occupy the fourth energy level?
3. Complete the following table.

sublevel	s	p	d	f
l value				

4. How many sublevels are there in the third energy level?
5. How many electrons can occupy any single orbital?
6. Complete the following table for the sublevels represented by the following quantum numbers.

n	2		4	4	5
l	0	2		3	
sublevel designation		$3d$	$4p$		$5s$

7. When $n = 5$, what are the possible values for l?
8. When $l = 2$, what are the possible values of m?

5:2 ORDER OF FILLING SUBLEVELS

The **electron configuration** of an atom is used to describe the electron distribution in the sublevels. Each sublevel symbol is written following a coefficient that represents the energy level containing the sublevel. Each sublevel symbol has a superscript on the right giving the number of electrons in the sublevel. For example, the electron configuration of the boron atom (atomic number 5) is written $1s^22s^22p^1$.

The order of filling corresponds to the increasing energy of the sublevels. By filling the sublevels of the lowest energy first, we have a model of an atom in the ground state. In many atoms with higher atomic numbers, the sublevels are not regularly filled. There is a rule of thumb that will give a correct configuration for most atoms in the ground state. We will explore the exceptions more fully in the next chapter. This rule of thumb is the **arrow diagram** and is shown in Figure 8-2. If you follow the arrows from tail to head, listing the orbitals passed as you move from left to right, you can find the electron configuration of most atoms.

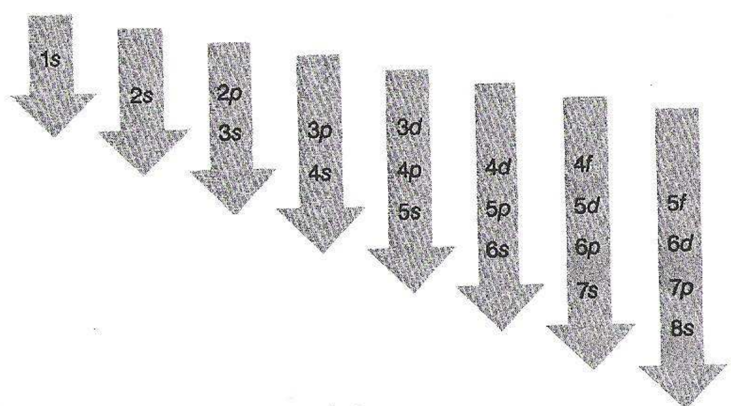


FIGURE 5-2. OR LOOK AT 5-3 ON LAST PAGE

Example 1

Write the electron configuration of arsenic ($Z = 33$).

Solving Process:

The arrow diagram above gives us the order $1s$, $2s$, $2p$, $3s$, $3p$, $4s$, $3d$, $4p$. The sublevels are then filled to capacity with the 33 electrons present in arsenic beginning with $1s$, then $2s$, and so on. The final 3 electrons are placed in the $4p$. The electron configuration is $1s^22s^22p^63s^23p^64s^23d^{10}4p^3$.

The sum of the superscripts equals the atomic number, 33.

PROBLEMS

9. Which of the following show the correct order of filling?
   - a. $1s2s2p$
   - b. $1s2s2p3s3p$
   - c. $1s2s3s$
   - d. $1s2s2p3s3p4s$
   - e. $1s2s2p3p3d4s$
   - f. $1s2s2p3s3p4s4p$
10. Write the name of the element represented by each of the following configurations.
    - a. $1s^22s^22p^5$
    - b. $1s^22s^22p^63s^2$
    - c. $1s^22s^22p^63s^23p^64s^23d^{10}4p^1$
    - d. $1s^22s^22p^63s^23p^4$
11. Write the electron configuration for each of the following elements using the diagonal rule.
    - a. aluminum ($Z = 13$)
    - b. iron ($Z = 26$)
    - c. cadmium ($Z = 48$)
    - d. carbon ($Z = 6$)
    - e. barium ($Z = 56$)
    - f. hafnium ($Z = 72$)

5:3 ORBITAL FILLING DIAGRAMS

The electron configuration gives the number of electrons in each sublevel but does not show how the orbitals of a sublevel are occupied by the electrons. The result of Hund's Rule predicts that one electron enters each orbital of a sublevel before any orbital is doubly occupied. For example, the electron configuration for nitrogen is $1s^22s^22p^3$. Nitrogen has three electrons in the $2p$ sublevel, and each of these electrons occupies a separate orbital. In the orbital filling diagram each box stands for an orbital. Arrows are used to indicate the direction of electron spin.

Example 2

Construct an orbital filling diagram for fluorine ($Z = 9$).

Solving Process:

Step 1. Write the electron configuration using the diagonal rule.

$$1s^22s^22p^5$$

Step 2. Construct an orbital filling diagram using a box for each orbital. Use arrows to represent the electrons in each orbital.

$1s$	$2s$	$2p$		
⇅	⇅	⇅	⇅	↑

Recall that each electron occupies an empty orbital within a sublevel, rather than pair with another.

5:4 ELECTRON DOT DIAGRAMS

The Lewis electron dot diagram is useful when showing how atoms bond together. In these diagrams the outer energy level electrons, those with the largest value of *n*, are represented by dots placed around the letter symbol of the element.

Example 3

Write the Lewis electron dot diagram for selenium ($Z = 34$).

Solving Process:

Step 1. Write the orbital filling diagram for the outer energy level of selenium using the diagonal rule.

$1s^22s^22p^63s^23p^64s^23d^{10}4p^4$

4s	4p		
⇅	⇅	↑	↑

Step 2. The symbol of the element represents the nucleus and all the electrons except those in the outer energy level. Each "side" (above, below, left, right) of the symbol represents an orbital. Draw dots on the sides to represent only the outer electrons (4*s* and 4*p*). Show them as paired or unpaired based on the orbital diagram.

:Ṡe·
  ··

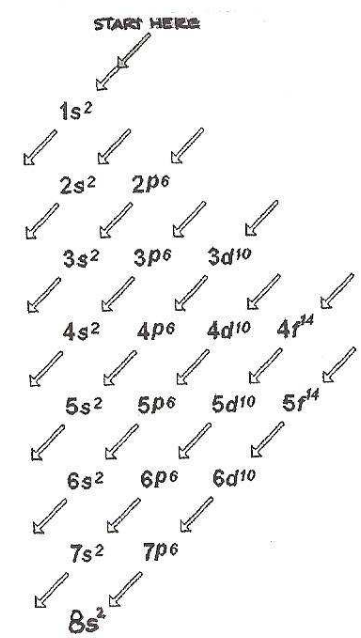
PROBLEMS

12. Predict electron configurations using the diagonal rule for atoms of the following elements.
    a. Li b. N c. Be d. O e. B f. F g. C h. Ne
13. Draw orbital filling diagrams for the elements listed in problem 12.
14. Draw Lewis electron dot diagrams for the elements in problem 12.

CHAPTER REVIEW PROBLEMS

1. Heisenberg stated that, at the same time, it was impossible to know what two things about an electron?
2. How many quantum numbers are there?
3. What letter denotes the quantum number for the principal energy level?
4. What four letters are used to represent the sublevels within a principal energy level?
5. What is the maximum number of electrons that may occupy one orbital?
6. Who stated that no two electrons in the same atom could have the same set of four quantum numbers?

7. The Lewis electron dot diagram is used to represent only which electrons in an atom?
8. What is the arrow diagram used to predict?
9. How many sublevels are possible in the third energy level?
10. How many orbitals are there in an *f* sublevel?
11. What is the maximum number of electrons that can occupy a *d* sublevel?
12. Which sublevel may contain a maximum of three pairs of electrons?
13. What must be true about the spins of two electrons occupying the same orbital?
14. Write the electron configuration for each of the following elements.
    a. lithium ($Z = 3$) b. radium ($Z = 88$) c. sodium ($Z = 11$) d. mercury ($Z = 80$) e. tin ($Z = 50$) f. krypton ($Z = 36$)
15. Draw the orbital filling diagrams for the following elements.
    a. titanium ($Z = 22$) b. sodium ($Z = 11$) c. aluminum ($Z = 13$) d. phosphorus ($Z = 15$)
16. Draw the Lewis electron dot diagram for the elements listed in problems 14 and 15.



SUBLEVEL	MAX e⁻
s	2
p	6
d	10
f	14