4.3: Electronic Structure of Atoms

Learning Objectives

- Describe how electrons are grouped within atoms into shells, subshells, and orbitals.

You now know that the periodic table is arranged in groups and periods (columns and rows) based on chemical and physical properties of the different elements. The first element, hydrogen has one proton and one electron and as you move right across the rows, each subsequent element has one additional proton and electron. You may have asked yourself, why are periodic trends observed across the rows and down the groups? Or, why do the rows have different numbers of elements, giving the table a unique shape?

These questions can be answered by learning more about the electrons in atoms. Although we have discussed the general arrangement of subatomic particles in atoms, we have said little about how electrons occupy the space around the nucleus. Do they move around the nucleus at random, or do they exist in some ordered arrangement?

In the early 1900's, scientists learned that an electron in an atom can have *only* certain fixed values of energy. We call this idea **quantized** energy. Much like the steps on a staircase do not have half or quarter levels in between, or the keys on a piano don't have notes in between, there are no energy levels in between each allowable energy value. Figure $4.3.1$ shows a simple model of an atom showing different rings around the nucleus of the atom that correspond to the idea of energy levels.

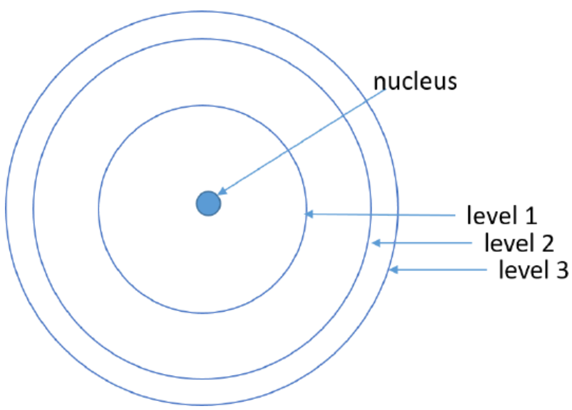

Figure $4.3.1$: A simple model to depict the idea of energy levels within an atom. Each ring represents a region of space that the electron in that energy level is confined within.

Figure $4.3.1$ does not give a full picture of where the electrons are located within an atom. For a better understanding we need quantum mechanics.

Quantum mechanics uses a mathematical treatment of the atom that explains the behavior of electrons as if they were acting as a wave, not as particles. It shows that within each level (shell), electrons are further arranged in sublevels and these sublevels are broken into specific regions of space that we call orbitals. So the exact location of the electron is in a specific orbital, that's in a specific subshell, that's in a specific shell. Additionally two electrons can occupy one orbital and when they do they align with opposite "spin" (more on that soon).

Four **quantum numbers** specify the location of each electron in the atom. Much like your home address can be used to locate you in a specific state, city, street, and house number, the first three quantum numbers identify approximately where electrons are in an atom. The fourth quantum number describes the orientation of an individual electron's electromagnetic field, its **spin**. The theory and mathematics behind these four quantum numbers are well beyond the scope of this textbook, however, it is useful to learn some of the basics in order to understand how atoms behave and interact with (react) with other atoms.

Electron Arrangements: Shells, Subshells, and Orbitals

Electrons are organized according to their energies into sets called **shells** identified by the integers 1, 2, 3, 4, 5, 6, & 7 (mathematically the value can be any integer but in practice we typically only use values up to 7). A simplified view of these shells is presented in Figure $4.3.1$ where each ring/level represents a shell. The lowest energy shell is shell 1 (level 1) and the energy values increase from there. Electrons in a higher-energy shell will spend more time farther from the nucleus than electrons in a lower-energy shell.

Shells are further divided into **subshells**, labeled *s*, *p*, *d*, or *f*. The first shell has only one subshell, *s*. The second shell has two subshells, *s* and *p;* the third shell has three subshells, *s*, *p*, and *d*, and the fourth shell has four subshells, *s*, *p*, *d*, and *f*. Within each subshell, electrons are arranged into different numbers of **orbitals**, an *s* subshell is made up of one *s* orbital, a *p* subshell has three *p* orbitals, a *d* subshell, five *d* orbitals, and an *f* subshell, seven *f* orbitals. Each orbital has a different shape and orientation around the nucleus (Figure 4.3.2), however, rather than representing an orbit, as the name suggests, orbitals define a boundary for the region of space where a given electron is most likely to be found. And again, a single orbital can hold up to two electrons each with a different spin.

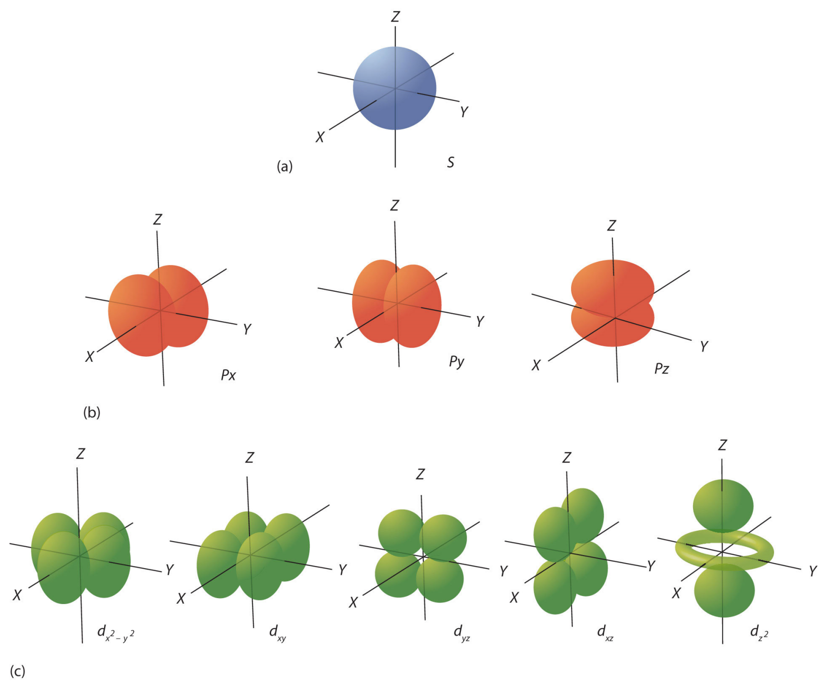

Figure 4.3.2: Electron Orbitals. (a) The lone *s* orbital in an *s* subshell is spherical in distribution. (b) The three *p* orbitals have two lobes, shaped kind of like dumbbells, each is oriented around the nucleus along a different axis. (c) The five *d* orbitals have four lobes, except for the d_{z^2} orbital, which is a "dumbbell + torus" combination. They are all oriented in different directions.

You can visualize or imagine that the second shell would have the all four orbitals shown in parts (a) and (b) of Figure 4.3.2 all centered around the nucleus and enclosed within the second ring of Figure 4.3.1. The third shell would include *another set* of all the same types (an s and three p) as well as the additional orbitals in row (c) of Figure 4.3.2.

It is important to note that according to quantum theory, there are specific *allowed* combinations of quantum numbers and others that are not allowed. For example, shell two can only have two subshells, *s* with one orbital and *p* with 3 orbitals, therefore, this shell can hold a maximum of eight electrons (four orbitals times two electrons each). It takes practice to learn the allowed combinations as shown in Table 4.3.1 but it is helpful to visualize the atom as a sphere with the nucleus in the center. Close to the nucleus, there is a smaller amount of space for electrons – a smaller shell. As the number of electrons increases, the shells that hold the electrons get larger and thus further away from the nucleus.

Table 4.3.1: Shells and Subshells

Shell (*n*)	Number of Subshells	Names of Subshells	Number of Orbitals (*per Subshell*)	Number of Electrons (*per Subshell*)	Total Electrons (*per Shell*)
1	1	*1s*	1	2	2
2	2	*2s* and *2p*	1, 3	2, 6	8

Shell (n)	Number of Subshells	Names of Subshells	Number of Orbitals (*per Subshell*)	Number of Electrons (*per Subshell*)	Total Electrons (*per Shell*)
3	3	*3s*, *3p*, and *3d*	1, 3, 5	2, 6, 10	18
4	4	*4s*, *4p*, *4d*, and *4f*	1, 3, 5, 7	2, 6, 10, 14	32

All of this information about the shell, subshell, and orbital is put together to make up the "address" for an electron and all of the addresses for all the electrons in an atom make up the **electron configuration**, which is described more later.