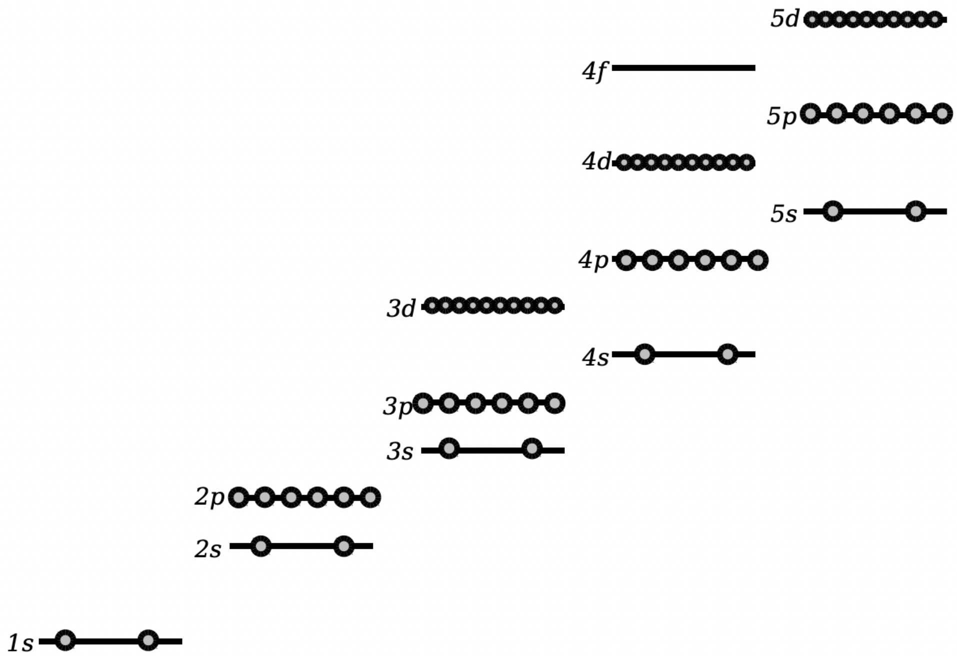
15.2: Filling Up Orbitals

You can use the diagram below to figure out where an element will fall on the periodic table. Start with the lowest energy states, and fill in available states with electrons. Keep filling them in until you have as many electrons as you need. If you have just a single spare electron in an s shell, then that is an element like Hydrogen, Lithium, or Sodium; it goes on the left column of the periodic table. As you fill in more and more levels, you move farther and farther to the right on the table. If you completely fill a p orbital, then you're on the very right side of the table, and the element you've constructed is a noble gas.



States available to electrons in atoms. States higher in the diagram are (usually!) states at higher energy, although the exact spacing on the diagram should not be interpreted as meaningful. Although not drawn, there are 14 states available in the $4f$ orbital. Additionally, to fill out the current modern periodic table, we'd need to extend this to include the $5f$, $6s$, $6p$, $7s$, and $7p$ orbitals.

Because the chemical properties of an element are approximately determined by how far away it is from a noble gas, constructing the periodic table in this manner means that every column should have somewhat similar chemical properties. Thus, each column on the periodic table is called a "Group". Each row on the periodic table is called a "Period". The name "Periodic Table" is not arbitrary. When something is periodic, it means that it has regular cycles. The period of the Earth's orbit around the Sun is about 365 days; after that much time, the Earth is back where it started. On the periodic table, it's element numbers that are periodic. After you add just enough electrons to fill up a p orbital, the next electron you add is as if you were starting over on a new shell.

However, there is a difference with the Periodic Table. In a simple orbit such as the Earth going about the Sun, each period is exactly the same length. However, on the Periodic Table of the Elements, periods get longer and longer. As you go to higher and higher values of n, there are more and more states available. At a given n, you can have values of l between 0 and $n-1$. Thus, for $n=1$, there are only two states available, and thus the first period has only two elements: H and He. At $n=2$, there are now eight states available (two s states and six p states), so there are eight elements in the period: Li, Be, B, C, N, O, F, and Ne. You might then expect there to be 18 elements in the third period, as for $n=3$ there are 18 states: two s states, six p states, and ten d states. However, it turns out that the $4s$ states are at a lower energy level than the $3d$ states. Thus, the third period only fills up the $3s$ and $3d$ states, and has eight elements just like the second period. In the fourth period, starting with Potassium, we fill in the $4d$, $3d$, and $4p$ states (approximately in that order), and now have eighteen elements. The same thing happens with f orbitals; it isn't until the sixth period, after the $6s$ states are filled, that the $4f$ orbitals start to get filled.

The fact that as you go to higher and higher periods, there are more and more states available before you can completely fill a p orbital, is what gives the periodic table its iconic "stepped" structure. The first step comes after Hydrogen and Helium. The first period only has the $1s$ orbital available, and only has two elements in it. The second and third periods each have 8 elements, filling up the $2s$, $2p$, $3s$, and $3p$ orbitals. The fourth period now has 18 elements in it, because in addition to the $4s$ and $4p$ orbitals, it also has to fill up the $3d$ orbitals.