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CHAPTER OVERVIEW

15: The Periodic Table of the Elements

In Section 13.4, we saw the example of a square potential well. In that example, there were three bound states. This is the solution for a single electron moving in that potential, so each of these levels represents a possible energy state available to that electron. There are in fact six total states available, because there are two spin states available to an electron as well. Under the approximation that electrons do not interact with each other, we could take exactly these energy levels and put up to six electrons in the potential well. Because electrons are fermions, no two electrons can be in the same state. (If we were putting bosons into the potential well, there would be no limit, as you can put multiple bosons in one state.)

The process of constructing the periodic table of the elements is similar to the process of filling up this square well with electrons. In the previous chapter, we saw that the states available to an electron are indexed by three quantum numbers: n, the principle quantum number, l, the total orbital angular momentum quantum number, and m, the quantum number indexing the z projection of orbital angular momentum. In addition, there is electron spin, allowing two electrons to go into each $|n, l, m\rangle$ state.

On the periodic table, the “atomic number”, usually indicated as the largest number in a display and often represented with the letter Z, is the total number of protons in the nucleus of the atom. The charge on the proton is exactly opposite the charge on the electron; whereas electrons have a charge of -1.602×10^{-19} C, protons have a charge of $+1.602 \times 10^{-19}$ C. Thus, for a neutral atom, the number of electrons is equal to the number of protons. Chemistry is all about the dynamics of electrons as atoms interact with each other, form bonds, trade electrons, and so forth. Therefore, from a chemical point of view, it might be more useful to think of Z as the number of electrons in a neutron atom of an element. (What if there is an additional electron added, making the atom negative, or if there is an electron removed, making the atom positive? In that case, we call it an ion, but we still name the ion based on the number of protons. A Chlorine atom with an extra electron would be called a negative Chlorine ion.)

Elements are constructed by filling in electron states until the number of electrons matches the number of protons in a nucleus. The number of states available at each shell is dictated by how angular momentum functions under quantum mechanics: as we saw in the previous chapter, l must be less than n, and m varies from $-l$ through l. If you put these two things together, it would be fair to say that angular momentum at the quantum level is responsible for the structure of the periodic table of the elements, the chemical properties of the different elements, and thus for chemistry and life as we know it. The number of states available is influenced, for instance, by the fact that angular momentum can only have definite states for projection along one axis at a time. The structure of the periodic table would be very different if x, y, and z angular momentum operators all commuted.