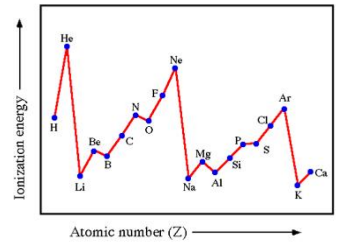
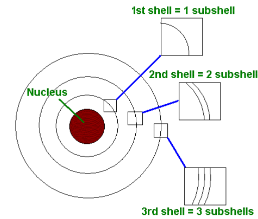
The Quantum Atom

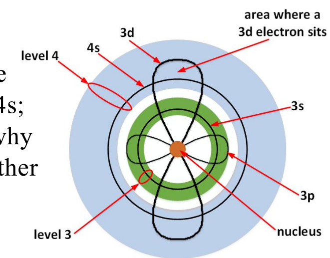


Studying periodic trends eventually reveals some very important irregularities. For example, why are noble gases so stable even though most of them only have 8 outer electrons which is not a full level. Also, some atoms within the same family had slightly higher first ionization energies than anticipated compared to elements in the period before and after meaning it is slightly harder to remove an electron from these atoms (e.g. family 2 and 5 elements). Likewise, family 4 non-metals actually had positive electron affinities that were higher than expected. In addition, family 1 metals can actually can have positive electron affinities under the right conditions which means they will readily except an electron. Finally, family 5 non-metals have exceptionally low positive electron affinities.

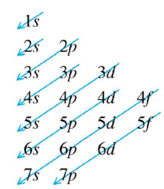


A breakthrough was made when comparing subtle energy differences of electrons within the same level. Apparently electrons do not sit randomly within a level, but actually occupy very specific locations within a level called **sub-levels**. This means subtle changes in energy can move an electron slightly within a level. Since level 1 can only hold 2 electrons and was discovered to only contain one spherical sub-level, the lowest energy sub-level or "s" can only hold 2 electrons.

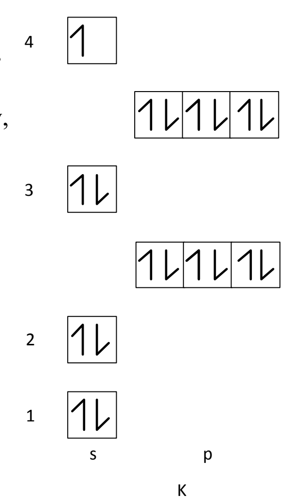
When level two was studied, the 8 electrons were found to distribute in a 2 to 6 ratio and the lower energy 2 electrons travelled spherically again. Thus, the s sub-level reappears and the newer higher energy sub-level with 6 electrons is the "p" sub-level. The fourth level was found to have a 2 to 6 to 10 to 14 electron distribution ratio adding up to the expected 32 electrons. Again, the lowest energy sub-level with it spherically travelling 2 electrons must be the s sub-level. The second lowest energy sub-level with its 6 electrons resembled p again. The second highest energy sub-level with 10 electrons is called "d" and the highest sub-level with its 14 electrons is called "f". The sub-levels are filled from lowest to higher energy as needed per level (Aufbau principle).



Once these, sub-levels were discovered, another interesting discrepancy appeared. The area in 3d where an electron most often is found is actually further away from the nucleus than 4s; that is, 3d is higher energy. This means it requires less energy to hold electrons in 4s which is why 4s is filled before 3d. However, these 3d electrons are really part of level 3 they interact with other level 3 electrons more than level 4; that is, these electrons share most of their properties with level 3 and not with level 4. Remember sub-levels are not concrete structures, but rather are locations and patterns of motion based on forces of attraction and repulsion.



This pattern of overlap repeats more often in progressively higher energy levels which would make it hard to track all this information. Fortunately, a system has been devised to predict the order of sub-level filling based on moving from lowest to highest amount of energy needed. Drawing the quantum atom would be quite difficult and very cluttered. Instead, a different representation is used; electronic configurations. Each energy level needed is represented by a number and each sub-level present in each level is represented by its appropriate letter written in order according to the Aufbau principle except with overlapping sub-levels in which case, the sub-levels are kept in their proper level. Finally, the number of electrons present in each sub-level is written as a superscript above each sub-level. For example, consider potassium with its 19 electrons: $1s^2 2s^2 p^6 3s^2 p^6 4s^1$. Notice that although level 3 does have a d sub-level, 4s is lower energy and is filled before 3d. Now consider scandium with its 21 electrons: $1s^2 2s^2 p^6 3s^2 p^6 d^1 4s^2$. Once 4s is full, 3d is used and is written as part of level 3. Short-forms of these electronic configurations can also be created by substituting the noble gas configuration for all inner electrons (the noble gas prior to the element). So potassium and scandium become $[Ar]4s^1$ and $[Ar]3d^1 4s^2$ respectively.



One final interesting discovery was that electrons exist in sub-levels as complimentary pairs; that is, pairs of electrons balance each other with opposing properties. So s with it 2 electrons has 1 pair of electrons, p has 3 pairs, d has 5 pairs and f has 7 pairs. These paired spots define how the electrons move within the sub-level are called orbitals so s has 1 orbital, p has 3 and etc. Finally, it was found that orbitals are filled one at a time before pairing (**Hund's rule**) to balance electron distribution within a level. Based on this, another quantum representation is the orbital filling diagram which displays increasing energy level on the y-axis and sub-level on the x-axis. Orbitals (boxes) do not overlap and electrons are shown as half-up/down arrows due to the complimentary nature of their properties. Consider some examples: