teachers'domain

The Quantum Mechanical Atom

Levels and Sublevels

Images displayed in all types of media depict atoms as dense spherical nuclei surrounded by orbiting electrons. It's a compelling image that's easy to remember. However, this image leaves out many important details, and so doesn't help us to fully understand actual atomic structure. For example, if a negative electron were simply in orbit around a positive nucleus, why wouldn't it be attracted to the positive charge and quickly spiral toward the center? There must be something keeping an atom from collapsing in on itself.

In the early twentieth century, physicist Niels Bohr proposed an explanation. Bohr's hypothesis said that electrons must occupy discrete orbits around a nucleus based on the energy level of those electrons. If an electron gains energy, it rises to a higher orbit; if it loses energy, it falls to a lower orbit. Within each of the orbits were suborbits, which corresponded to smaller variations in energy level. As part of his theory, Bohr proposed a systematic way for identifying the energy levels and sublevels and their corresponding orbits and suborbits.

Let's take a look at the table of Levels and Sublevels, starting from the nucleus and working outward: The levels (or shells) are numbered and the sublevels (or subshells) are indicated by the letters **s, p, d,** or **f.**

Levels and Sublevels

1	s			
2	s	p	d	
3	s	p	d	
4	s	p	d	f
5	s	p	d	f
6	s	p	d	f
7	s	p	d	f

You can see that the innermost zone, level 1, contains only one sublevel, **s.** Level 2 contains sublevels **s** and **p.** Level 4 is the first level that can contain all four sublevels: **s, p, d,** and **f.** Levels further outward from level 4 have the same sublevel configuration.

On any level, a single **s** sublevel exists by itself, containing two electrons. However, the other three sublevels are actually composed of three or more sublevel orbitals. For example, on any level, a **p** sublevel is actually made up of a group of three orbitals. Similarly, **d** sublevels are made up of a group of five orbitals, and **f** sublevels are composed of a group of seven orbitals. Each of these individual orbitals can contain a maximum of two electrons. Below is a summary of sublevels and the maximum number of electrons that they can contain:

Sublevel	Sublevel Groups							Total Electrons
s				**s**				1 • 2 = 2
p			**p**	**p**	**p**			3 • 2 = 6
d		**d**	**d**	**d**	**d**	**d**		5 • 2 = 10
f	**f**	**f**	**f**	**f**	**f**	**f**	**f**	7 • 2 = 14

In the simplest terms, this means that an **s** sublevel can contain as many as two electrons, a **p** sublevel can contain as many as six electrons and so on as shown in the last column of the table.

So the number of electrons in a given sublevel is expressed by writing the level number followed by the sublevel's letter, with the number of electrons in the sublevel written as a superscript. For example:

$3\mathbf{p}^2$ (There are 2 electrons in the **p** sublevel of level 3.)

$4\mathbf{d}^7$ (There are 7 electrons in the **d** sublevel of level 4.)

With this information, we can discover the reason for the periodic nature of elements, the "why" behind Mendeleyev's periodic table.

Electron Configuration

To better understand electron configuration, let's take a look at a specific element. Lithium, element number 3 on the periodic table, is a member of group IA, the alkali metals. Its atomic number, 3, is based on the three positive protons in its nucleus. These protons will, in turn, attract and hold three electrons. The arrangement of these electrons about its nucleus is what gives lithium its chemical properties. Let's see how those electrons are distributed.

Start by looking at the table of Levels and Sublevels. Then check the table of Total Electrons to see how many electrons each level can contain.

Level 1 contains a single **s** sublevel = 2 electrons

Lithium has three electrons, which leaves one electron unaccounted for. The table of Levels and Sublevels shows us that we have used all of the available sublevels in level 1, so we move to the next level and find that our final electron will be a single electron in level 2, sublevel **s**. The electrons for lithium are recorded as $1\mathbf{s}^2\ 2\mathbf{s}^1$. You can check the electron count by adding the superscripts. The chemical nature of elements is due to the electrons in the outermost level, so lithium's highly reactive nature is a result of the **s**1 electron in its outermost level.

Sodium, element number 11, is also an alkali metal. It's a member of the same group IA and has similar properties. The number of electrons in the first two levels of an atom of sodium is as follows:

Level 1 contains a single **s** sublevel = 2 electrons

Level 2 contains **s** and **p** sublevels = 2 + 6 = 8 electrons

So far, levels 1 and 2 have given us 10 electrons. But sodium has 11 electrons. The table of Levels and Sublevels again shows us that we have used all of the available sublevels in levels 1 and 2, so we move to the next level and find that our last electron will be a single electron in level 3, sublevel **s**. We can record all of the sublevels as before, and check our electron count by adding superscripts:

$$1\mathbf{s}^2\ 2\mathbf{s}^2\ 2\mathbf{p}^6\ 3\mathbf{s}^1$$

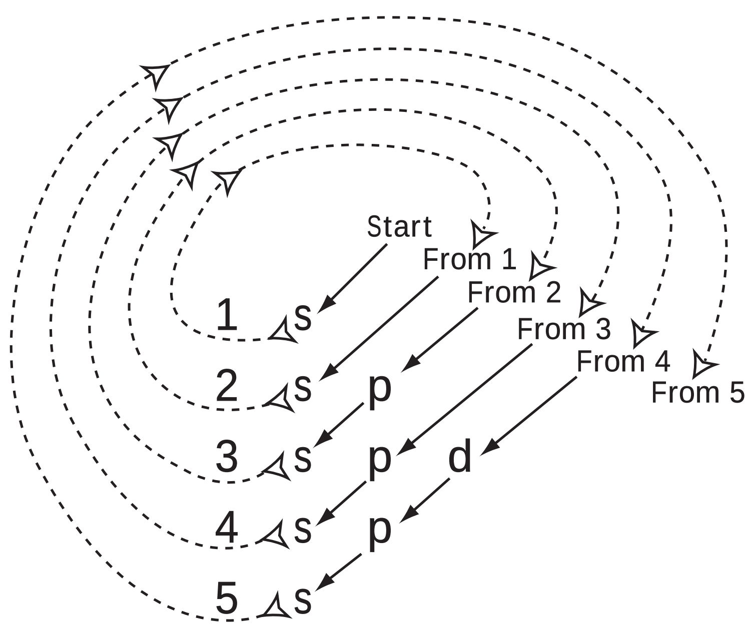
Note that the last added electron is $3\mathbf{s}^1$. From the outside, sodium looks just like lithium with a single $\mathbf{s}^1$ electron in its outermost level. Can you see why Mendeleyev put them in the same column?

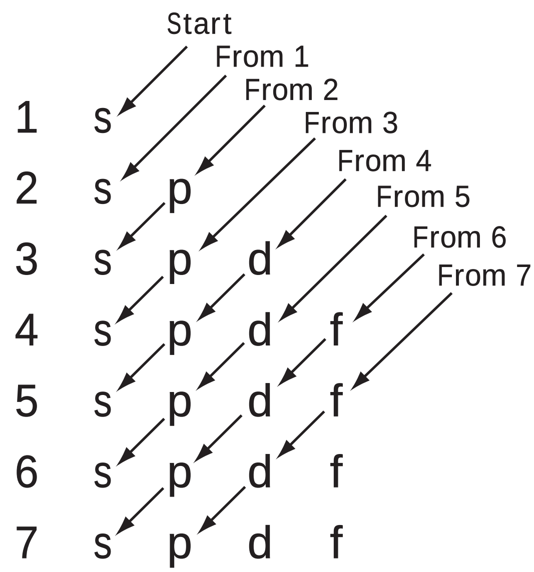
Repeating Electron Patterns

We're beginning to see that the repeating properties of elements in the periodic table are due to the repeating arrangement of electrons around the nucleus. Indeed, these and similar patterns appear throughout the periodic table. However, not all cases are as simple as those of lithium, sodium, and other elements with low atomic numbers.

For all elements after calcium, number 20 on the periodic table, the nearness of energy between sublevels blurs the order of electron selection. Scanning through the elements, beginning with atomic number 21, scandium, we see **s** sublevels being filled before **d** sublevels of the previous levels are filled. This is because the **s** sublevel of level 4, for example, is lower in energy than the **d** sublevel of level 3. The nearness in energy between **s** and **d** sublevels makes it important to read the Levels and Sublevels table in a special way. Reading straight across levels as we did in the previous examples works only up to 3**p**. After that we need to switch the fill order of **d** and **s** sublevels. Here's how to do it:

Follow the arrow from Start. Record the level from the bold number to the left, and the sublevel from the letter to the right. Follow the direction of the loops, recording levels and sublevels as you go. When you reach an s sublevel, note the level and then loop around to the matching *From* number. Here's an example: 1s, 2s, 2p, 3s, 3p, 4s (not 3d), 3d, 4p, 5s, 4d





Here is the quantum number string for element number 50, tin, in the order that this pattern produces:

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^2$

Note that the superscripts add up to 50. We can assume that tin will have properties similar to other elements with p^2 electrons in their outer level.

Abbreviated Configurations

Unfortunately, as much as this type of notation tells us about the electron configuration of tin, it's awfully cumbersome. We couldn't possibly fit it into the small box of a periodic table — unless we shortened it. As we've learned, each element's configuration builds on the previous elements' configurations. Therefore, to save space, chemists often use the symbol for the previous noble gas to represent a large part of the configuration of the element in question. For example, the nearest previous noble gas to tin is krypton, with a configuration as follows:

$$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$$

It is therefore possible to write an abbreviated configuration for tin as

$$[Kr]\ 5s^2\ 4d^{10}\ 5p^2$$

The same is true for nearly all elements of the periodic table. Sodium, for example, can be written as

$$[Ne]\ 3s^1$$

Lithium's abbreviated configuration is

$$[He]\ 2s^1$$

Bromine's abbreviated configuration is

$$[Ar]\ 4s^2\ \ 3d^{10}\ 4p^5$$