Teacher Background
Chapter 4 Lesson 3

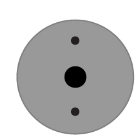
There are several ways to model the electron energy levels of atoms. Some middle school texts show the electrons in pairs on an energy level. This pairing of electrons is intended to suggest information about the substructure *within* energy levels. This substructure is made up of regions called *orbitals* which comprise each energy level. The shape and size of the orbital is defined by the space around the nucleus where there is a high probability of finding electrons. There can be a maximum of two electrons in any orbital so showing electrons in pairs on an energy level model is an attempt to suggest information about the orbitals within the level.

In Middle School Chemistry, we chose to spread electrons out evenly on energy levels to indicate only the *number* of electrons on a level and not to suggest anything about the substructure of orbitals *within* energy levels. An understanding that the different energy levels can accommodate a certain number of electrons seems enough for students in middle school. They will see more refined models in high school and college when they learn more details about the orbitals within energy levels.

Some teachers might like to use a different model that shows more details of orbitals because it is more complete, even if they do not intend to explain those aspects of the model in much detail. Another argument is that a model showing paired and unpaired electrons may be useful for certain discussions about bonding. Other teachers may be more comfortable showing a less-detailed model even if it leaves out certain aspects of energy levels because they do not intend to discuss those details and they intend to handle bonding in a more general way.

No model can be complete and accurate for all purposes, and all have limitations. All models involve aspects of judgment and compromise. A good model focuses on the important points without too much to distract from those main features. The model you choose will have a lot to do with how much you think is important to explain and what the students are able to understand.

Some energy level models you might see and what they represent
For helium (atomic number 2), the energy level model in Middle School Chemistry is shown here:
Helium has two electrons on the first energy level.

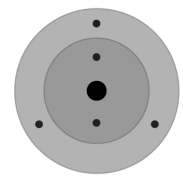

Helium

Some other middle school texts might show an energy level model for helium like this:

Helium

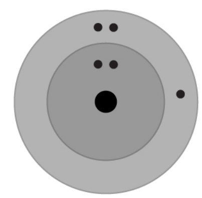
The *first* energy level has only one orbital. This is known as the 1s orbital. The “1” means that it is in the first energy level and the “s” stands for an orbital within that energy level with a particular shape. This 1s orbital can hold up to two electrons. So, helium has its two electrons in the 1s orbital. The practice of showing the electrons together or *paired* in an energy level is meant to indicate how many orbitals in that level have been completely occupied by two electrons. For the first energy level, the pairing is not very useful for showing which orbitals are full and which aren’t because there is only one orbital. But it becomes more useful for atoms that have more orbitals where some orbitals may be filled and others not.

For boron (atomic number 5), the energy level model in Middle School Chemistry is:



Boron

Boron has 2 electrons on the first energy level and 3 electrons on the second level. Some other middle school texts might show an energy level model for boron like this:

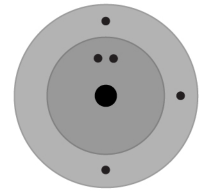


Boron

The model shows that boron has two electrons in the 1s orbital of the first energy level which are shown as paired. It also has 3 electrons in the second energy level.

The second energy level is made up of four orbitals. There is a spherical orbital called 2s. The “2” means that it is in the second energy level. It is like the 1s orbital but is further from the nucleus. The second energy level has 3 other orbitals that are all the same shape and distance from the nucleus but oriented in different directions. These orbitals are called 2p. The “p” orbitals are a different shape than the “s” orbitals. The 2s orbital can hold up to two electrons and each of the 2p orbitals can also hold up to 2 electrons. So the second energy level can hold up to eight electrons in its four orbitals. In this model of boron, two electrons are shown as paired in the 2s orbital and the last electron is shown in one of the 2p orbitals.

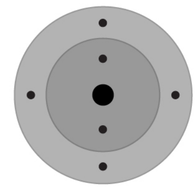
Another middle school text might show a model of boron like this:



Boron

Here, they paired the electrons in the 1s orbital but did not show the detail of pairing the electrons in the 2s orbital of the second energy level. They chose to spread the three electrons out on the second energy level.

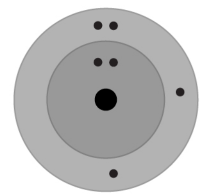
For carbon (atomic number 6), the energy level model in Middle School Chemistry is:



Carbon

Carbon has 2 electrons on the first energy level and 4 on the second. Some other middle school texts might show a model of carbon like this:

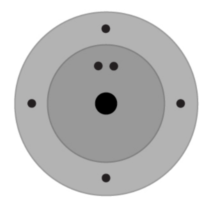
This model shows that carbon has two electrons in the 1s orbital of the first energy level which are shown as paired. It also has 4 electrons in the second energy level. In this model, two electrons are shown as paired in the 2s orbital and the other two electrons are shown separately or unpaired.



Carbon

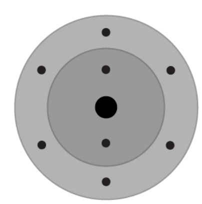
This is done to indicate that each of the electrons is in a separate 2p orbital. One of the details of orbitals is that an electron goes into an empty available orbital of the same type before it goes into an orbital that already has an electron in it.

Another middle school text might show a model of carbon like this:
This model pairs the 1s electrons but spreads out the four electrons in the second energy level regardless of what orbital they are in.



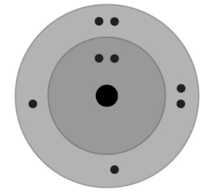
Carbon

For oxygen (atomic number 8), the energy level model in Middle School Chemistry is:



Oxygen

Oxygen has 2 electrons on the first energy level and 6 on the second. Oxygen is an interesting example because the other two types of models come out with the same result which looks like this:



Oxygen

Here, the electrons are paired in the 1s orbital. In the second energy level, whether the electrons are paired in the 2s to begin with or whether they are spread out and only paired after placing 1 electron in each of the four orbitals and then adding the last two electrons to make two pairs, the result is the same.

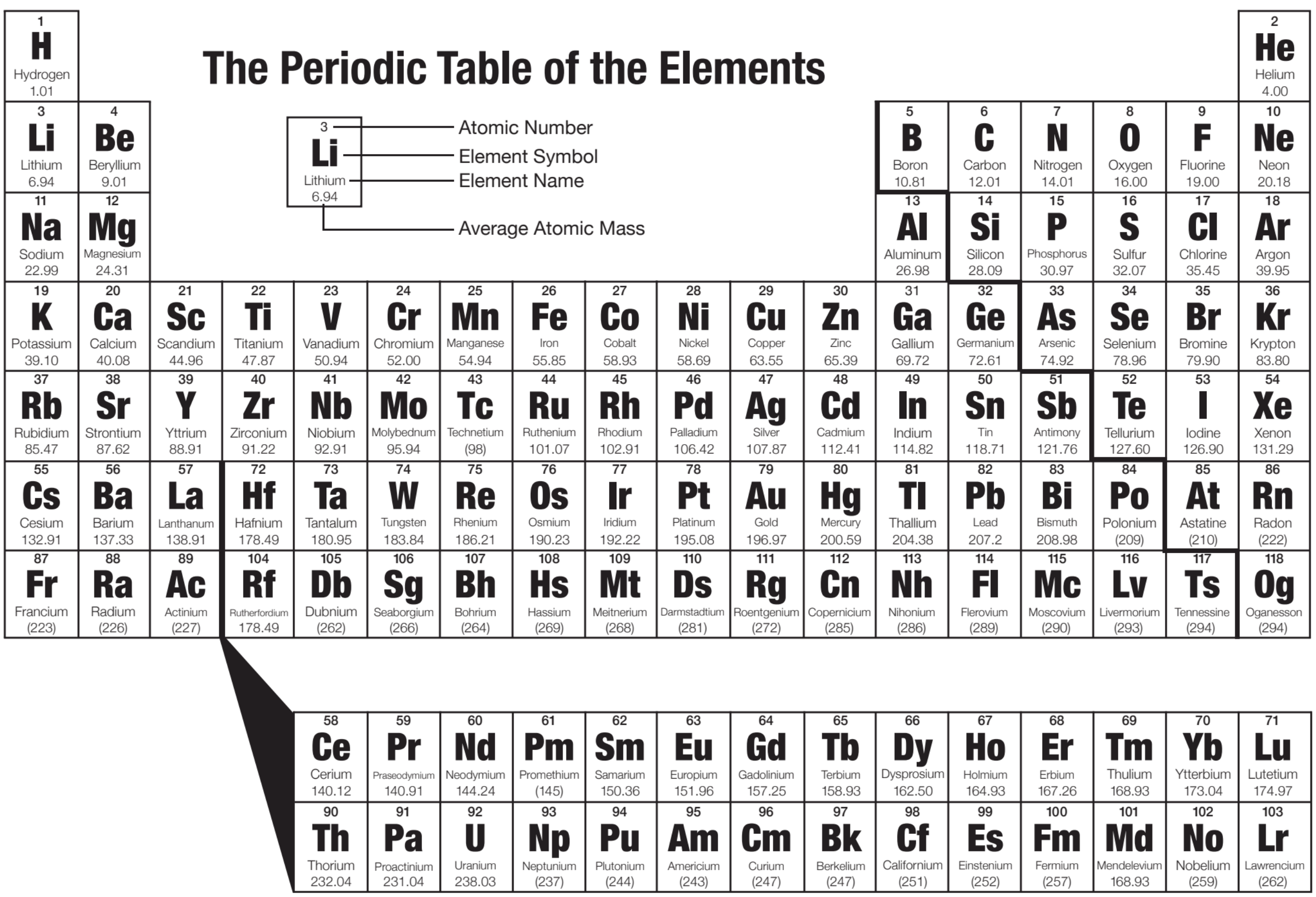
If the energy level models in Middle School Chemistry are different than those in your textbook, you can use either one to teach that energy levels only have a certain number of electrons. You could also use the difference to suggest that there is more detail about energy levels that students may learn about later.

Teacher Background

Chapter 4 Lesson 3

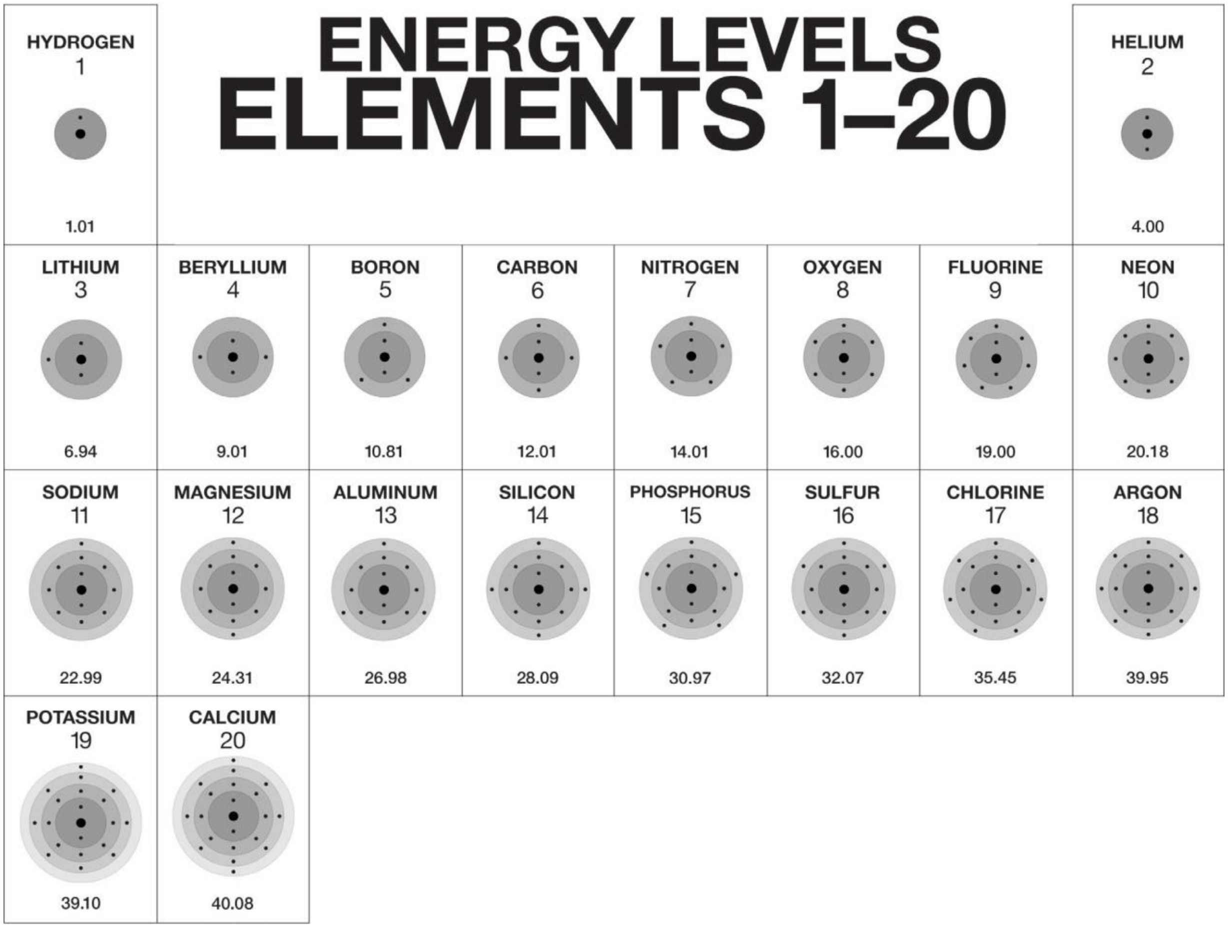
What determines the shape of the standard periodic table?
One common question about the periodic table is why it has its distinctive shape. There are actually many different ways to represent the periodic table including circular, spiral, and 3-D. But in most cases, it is shown as a basically horizontal chart with the elements making up a certain number of rows and columns. In this view, the table is not a symmetrical rectangular chart but seems to have steps or pieces missing.

The key to understanding the shape of the periodic table is to recognize that the characteristics of the atoms themselves and their relationships to one another determine the shape and patterns of the table.



A helpful starting point for explaining the shape of the periodic table is to look closely at the structure of the atoms themselves. You can see some important characteristics of atoms by looking at the chart of energy level diagrams. Remember that an energy level is a region around an atom's nucleus that can hold a certain number of electrons.

The chart shows the number of energy levels for each element as concentric shaded rings. It also shows the number of protons (atomic number) for each element under the element's name. The electrons, which equal the number of protons, are shown as dots within the energy levels. The relationship between atomic number, energy levels, and the way electrons fill these levels determines the shape of the standard periodic table.

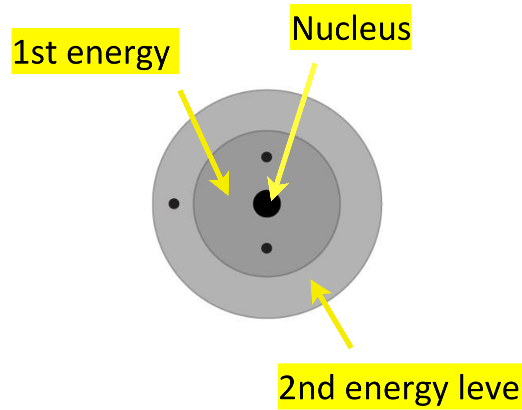


What determines the sequence of the elements?
One of the main organizing principles of the periodic table is based on the atomic number (number of protons in the nucleus) of the atoms. If you look at any row, the atoms are arranged in sequence with the atomic number increasing by one from left to right. Since the number of electrons equals the number of protons, the number of electrons also increases by one from left to right across a row.

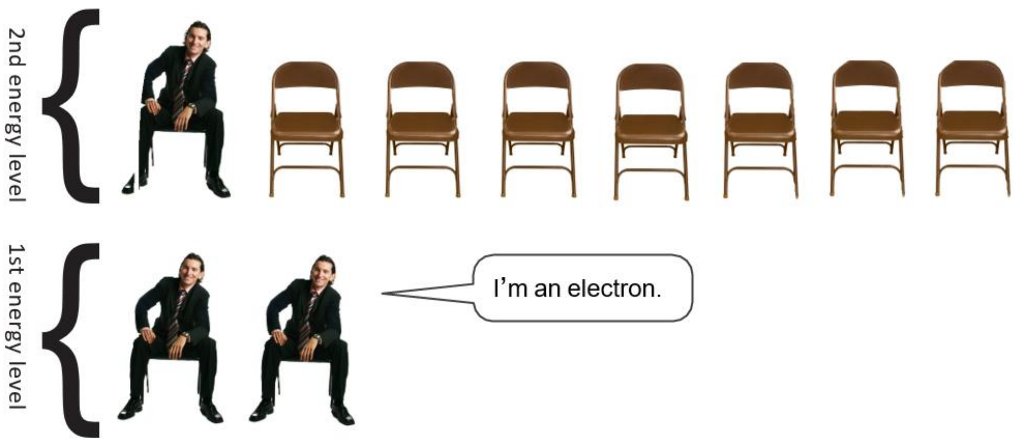
What do the rows represent?
The rows in the periodic table correspond to the number of energy levels of the atoms in that row. If you look at the chart, you can see that the atoms in the first row have one energy level. The atoms in the second row have two energy levels and so on. Understanding how electrons are arranged within the energy levels can help explain why the periodic table has as many rows and columns as it does. Let's take a closer look.

Electrons and Energy Levels

Every atom contains different energy levels that can hold a specific number of electrons. For a moment, let's imagine the simplest possible scenario: once all the positions are occupied within one energy level, any remaining electrons begin filling positions in the next energy level.



To picture this, imagine people filling rows of chairs in an auditorium. If each person sits next to another person until one row is filled, any remaining people must begin taking their seats in the second row, and so on.

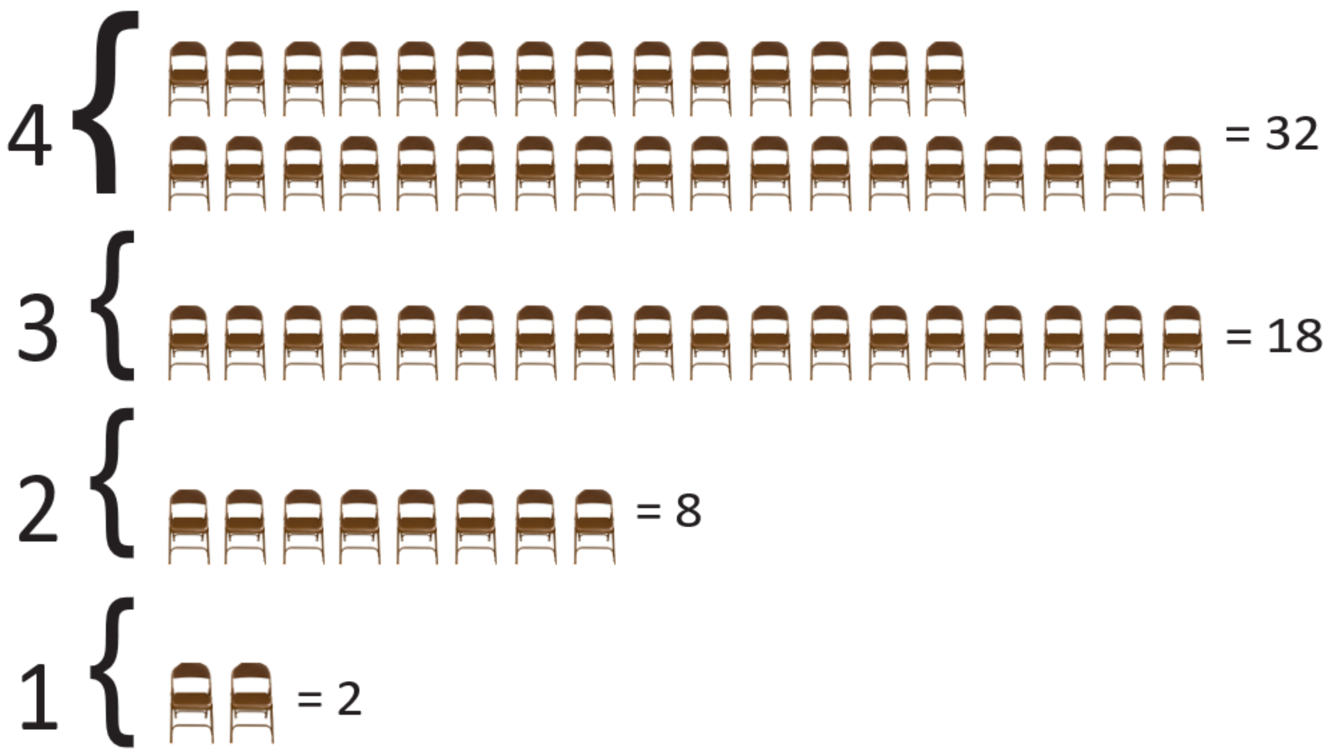


Not so bad, right? In general, this simple case is a helpful analogy. Electrons fill a given section until it is full, and then any more electrons move on to another unoccupied section where they continue filling there. Electrons begin filling the lowest energy level (closest to the nucleus) and then move on to higher energy levels (further form the nucleus). Unfortunately, the actual process is a bit more complicated. Let's see why.

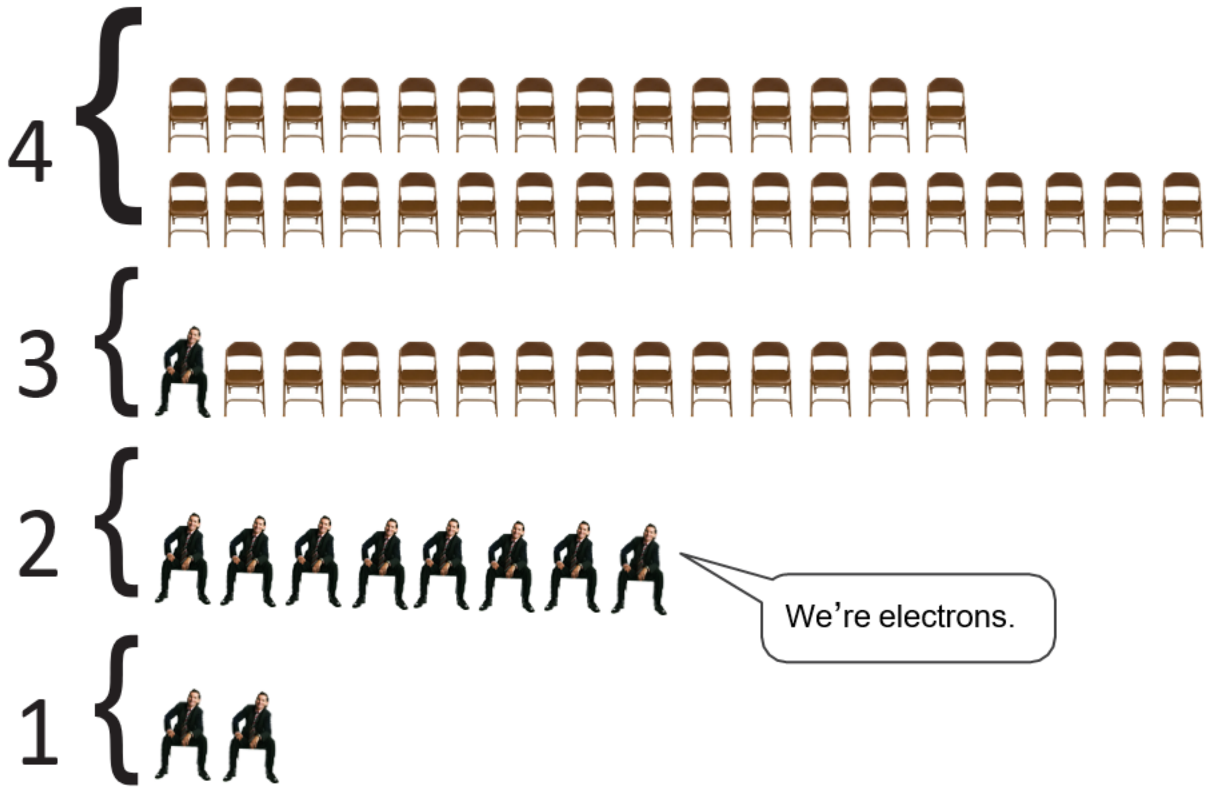
Energy Levels Can Hold Different Numbers of Electrons

One thing that is slightly tricky about electrons filling these energy levels is that not all the energy levels can hold the same number of electrons. While the first energy level can hold only 2 electrons, the second energy level can hold 8, the third can hold 18, and the fourth can hold 32. We'll stop there for now.

If we return to our rows of chairs analogy, it would be as if the first row was shorter than the second or third or fourth rows, so that after 2 people, any people remaining would have to begin occupying the second row. Then, if the second row were longer than the first row (but shorter than the third row), after 8 more people had been seated, any remaining individuals would have to begin occupying the third row.



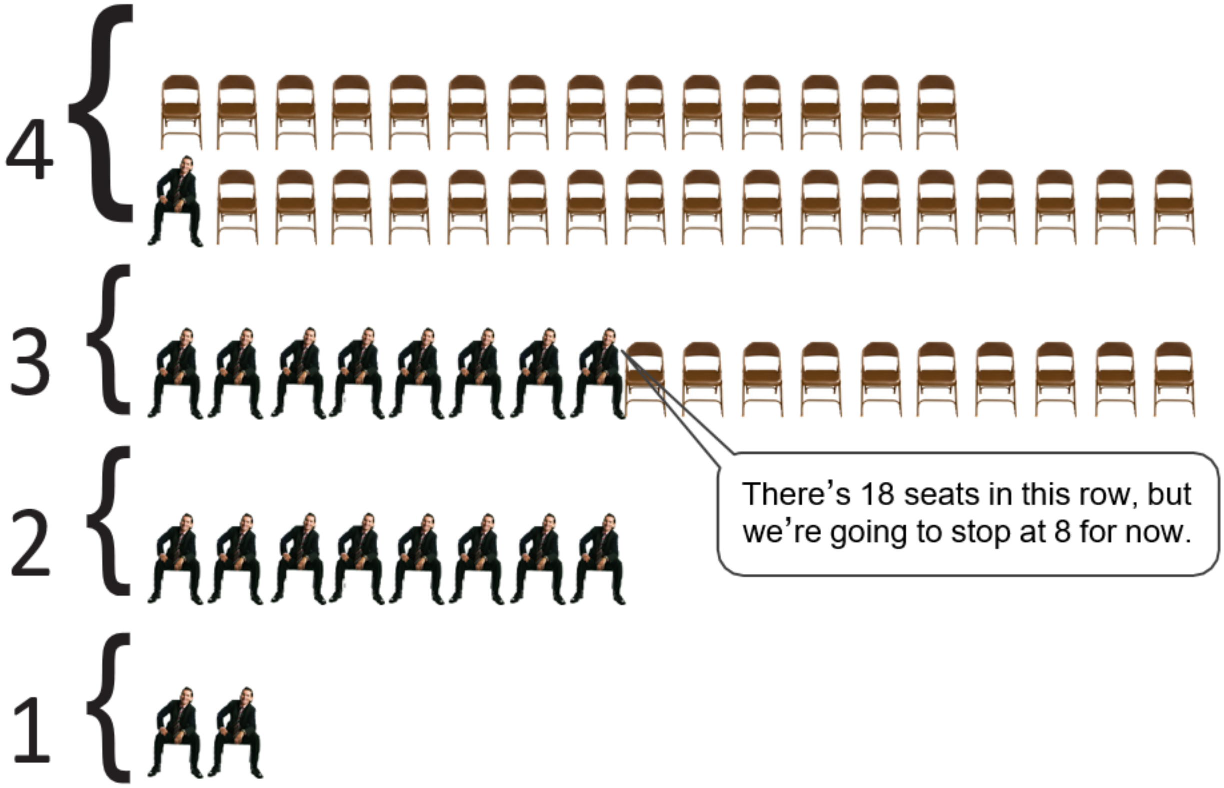
Extending our analogy of theater patrons as electrons, let's look at how the element sodium, with its 11 electrons, might fill these energy levels.



Because sodium has 11 electrons, it fills up the first energy level, which can hold only 2 electrons. It also fills up the second energy level, because it can only hold 8. Together, the first and second energy levels can hold a total of 10 electrons. Sodium has 11 electrons, so that final remaining electron that can't be accommodated by the first and second energy level begins filling in the third energy level. This pattern generally holds for the first 18 elements, up through argon, which has 18 electrons.

Energy Levels are Further Divided into Sections

But something funny happens beginning with potassium. Potassium has 19 electrons. Because the first, second, and third energy levels can hold a total of 28 electrons (2+8+18=28) it would seem that all the electrons of potassium could be "seated" within the third energy level. It turns out, however, that even though the third energy level has a total capacity of 18, only 8 "seats" are filled before the electrons begin filling the fourth energy level. So, potassium would fill up the energy levels like this:

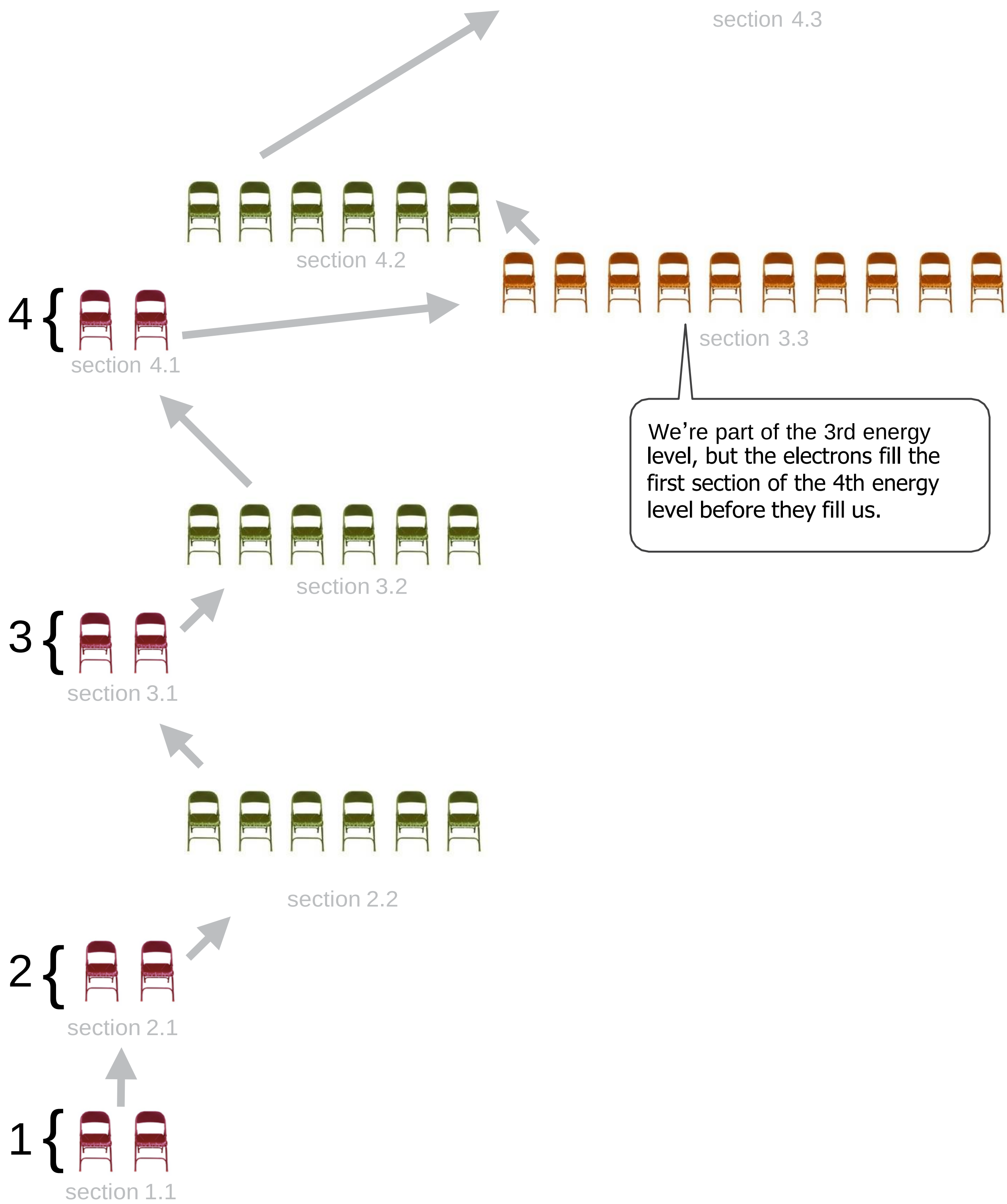


Whoa. *Whoa*. That’s crazy. Why does *that* happen?

This is the second complication with our simple chairs analogy. It turns out that in addition to distinct energy levels (first, second, third, etc.) each energy level is further divided into sections where electrons can be found.

In terms of our analogy, the first row would have just one section. The second row would have two sections. The third row would have 3 sections and the fourth row would have four sections. As you can see, the number of sections an energy level has is equal to the number of that energy level.

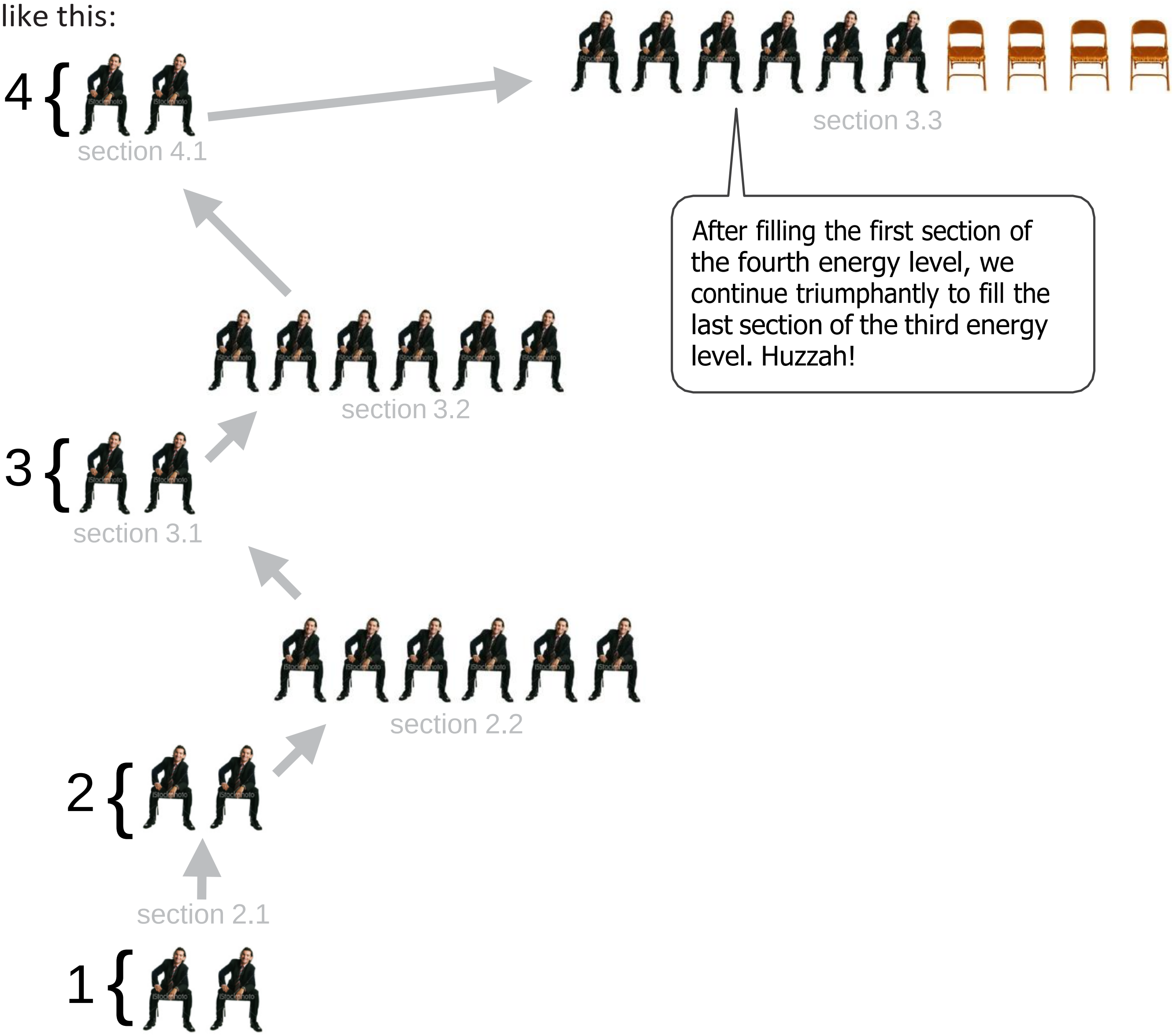
The reason why that last electron from potassium begins filling the fourth energy level rather than continuing to fill the third energy level is that the first section of the fourth energy level is actually closer (or at lower energy) than the last section of the third energy level (the last 10 “seats”). So, really, our chairs would now look something like this:


section 4.3
section 4.2
4
section 4.1
section 3.3
We’re part of the 3rd energy level, but the electrons fill the first section of the 4th energy level before they fill us.
section 3.2
3
section 3.1
section 2.2
2
section 2.1
1
section 1.1

Admittedly, this doesn't look much like rows of chars in an auditorium anymore, but the idea is still the same. Electrons will continue filling energy levels, one section at a time, until all the electrons are used up. When one section of the next energy level is actually lower in energy than the next section of the same energy level, the electrons will begin filling there. This is what we depicted in the diagram for potassium. Its last electron filled the first section in the fourth energy level, because that section was actually closer (at lower energy) than the last section of the third energy level.

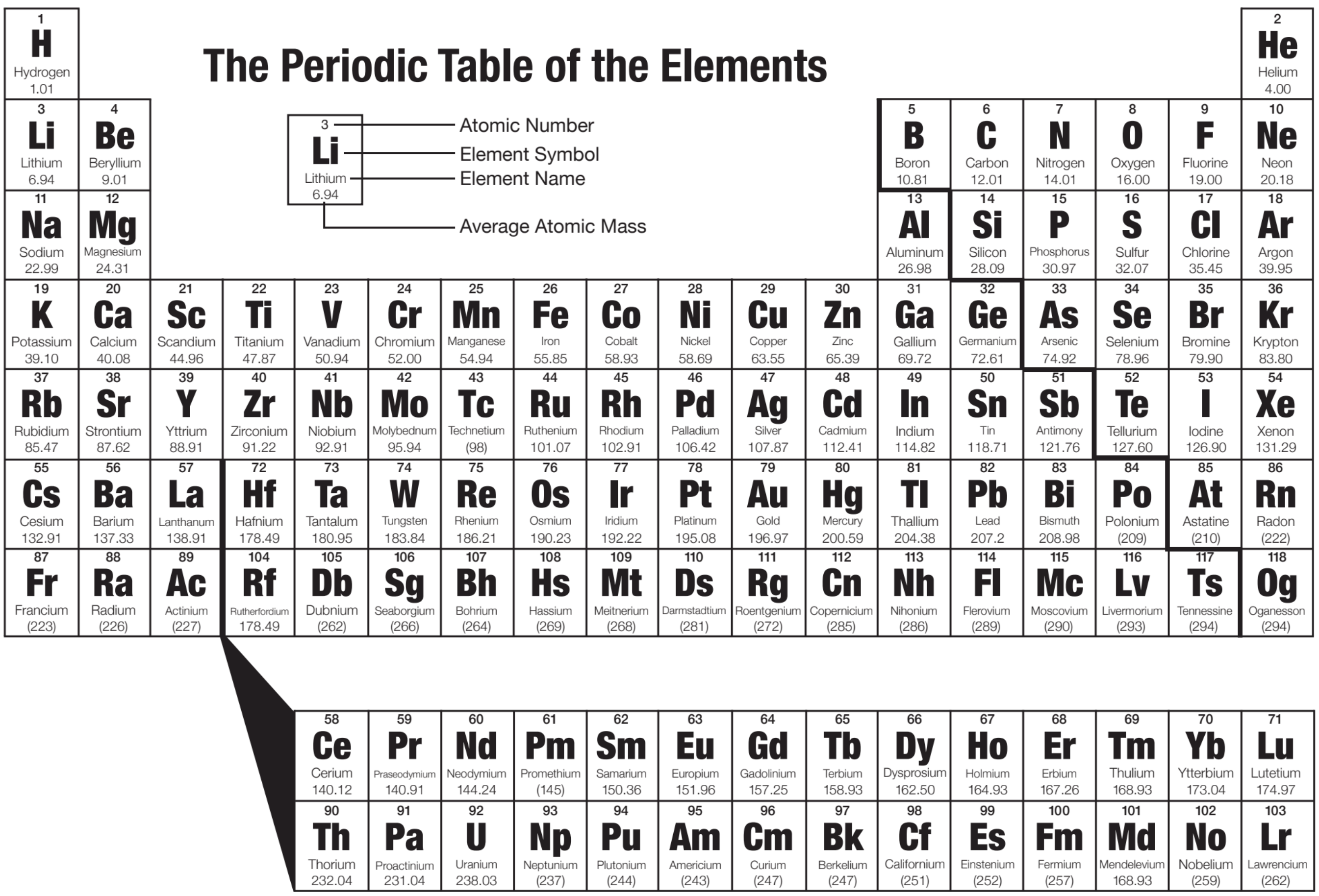
Eventually, the electrons will continue filling the empty section in the third energy level. The idea is exactly what we've just described. Unusual as it might seem, in some cases, the first section of the next energy level is filled before the electrons continue to fill the last section of the preceding energy level.

Consider, for example, the element Iron. Its 26 electrons would fill energy levels like this:



Whew! So what does all of this mean?

Mainly this: understanding how electrons fill energy levels can help us to understand why the periodic table has as many rows as it does. Each row can roughly be thought of as starting a new energy level. As we proceed across a row, electrons fill energy levels in sections according to where they can be at the lowest energy. So, rather than the row continuing on forever, the periodic table begins a new row which signifies that the electrons in the elements in the next row begin filling a new energy level.



As we saw, sodium doesn’t fall to the right of neon on the periodic table just because sodium has more electrons than neon has. Because sodium begins placing its electrons in a new energy level, it is positioned on the far left side at the beginning of a new row.

If we understand a few of the rules about energy level capacity and filling, we can begin to make sense of the periodic table’s unusual shape. Why does the first row only consist of two elements? Well, it’s because the first energy level can only hold two electrons, and helium, with an atomic number of two, has exactly two electrons. All elements after it have more than 2 electrons, and so they must continue filling their electrons at higher energy levels.

Why does the second period consist of eight elements? It's because the second energy level can only hold eight electrons. If we add in the two the first energy level can hold, the first and second energy levels combined can hold 10 electrons, and neon, the last element of the second period, has exactly 10 electrons.

Though it's a little tricky, potassium begins placing its electrons in the fourth energy level (even with 10 "seats" still available in the third energy level) because the first section of the fourth energy level is lower in energy than the last section of the third energy level.

The number of rows the periodic table has corresponds to the number of energy levels needed to hold all of the electrons of an atom with the greatest known number of electrons.

And what about these rows hanging out at the bottom? What's their deal?
The other peculiar feature found in most copies of the periodic table are two mysterious rows, often situated below the rest of the table, which seem to have no relation to the rest of the elements. These rows are called the *lanthanide* series and *actinide* series, respectively.

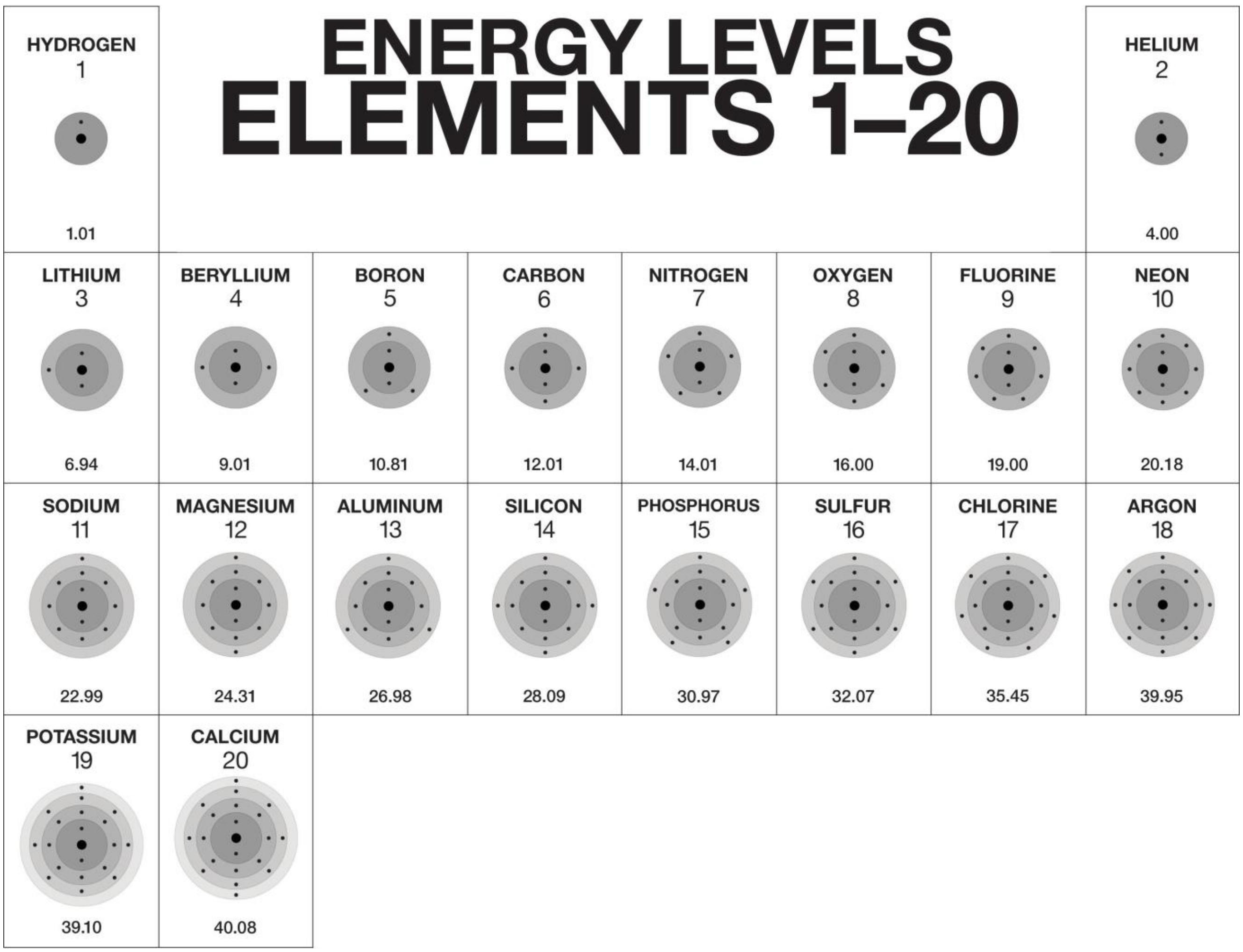
These rows are often placed below the rest of table simply as a convenience. In reality, the elements within the lanthanide series, beginning with the element lanthanum, actually belong alongside barium on the periodic table. Because this would make the table very wide, they are usually placed below the rest of the table so that the format of the periodic table fits more easily on a standard size poster or piece of paper. The same is true for the elements that comprise the actinide series. Beginning with the element actinium, these elements actually belong alongside radium, just below where the lanthanide series would be situated. Some periodic tables actually are formatted in this elongated version. As a convention, however, they are placed below for convenience.

Although alternative forms of the periodic table have been created, some taking unusual shapes like a series of concentric circles in an archery target, the conventional table with the familiar groups and periods is considered the standard.

Why do atoms in the same column have the same number of outer (valence) electrons?
If you think about how the energy levels fill up with electrons, and how the periodic

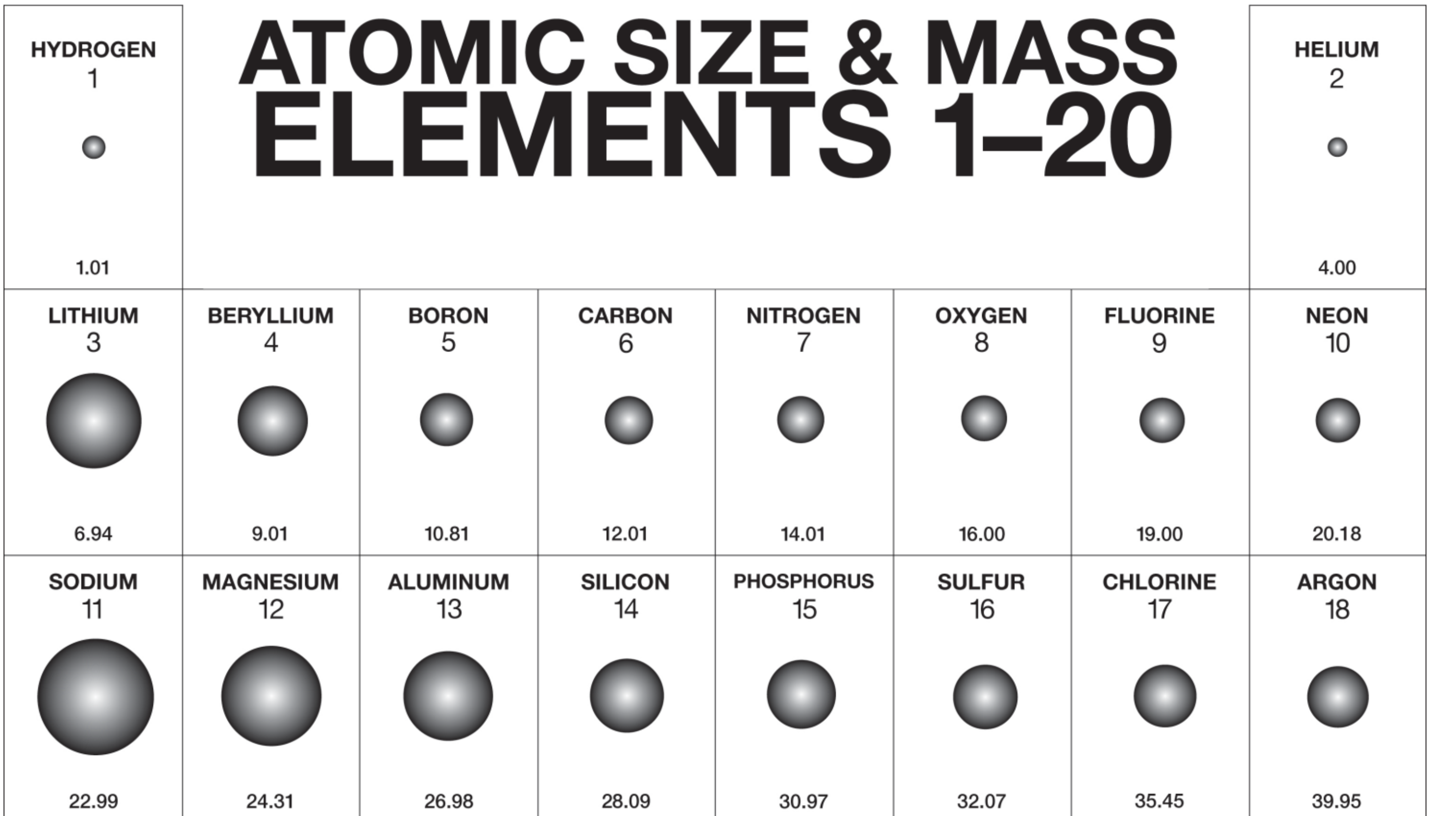
table is designed, you can see how certain atoms end up in the same column. An important point about the columns is that the number of electrons in the outer energy level, called *valence* electrons, will be the same for all the elements in that column.

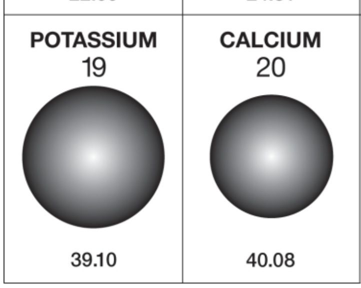
The periodic table is designed so that the first electron starting a new energy level starts a new row on the far left. Each new row starts after the outer energy level of the previous row has eight electrons. An exception to this is starting the second level after the first level has two electrons.
Let's look again at the energy level chart.



With these principles in mind, you can see why the atoms in the first column, which contains hydrogen (H), lithium (L), sodium (Na), and potassium (K), each have one electron in the outer energy level. In the second column, beryllium (Be), magnesium (Mg) and calcium (Ca), all have two valence electrons. The atoms in the column with boron (B) and aluminum (Al) all have three valence electrons. The atoms in the column with carbon (C) and silicon (Si) have four valence electrons. The rest of the columns follow this same pattern. The transition elements in the middle of the periodic table (not shown in the chart) for the most part have two valence electrons.

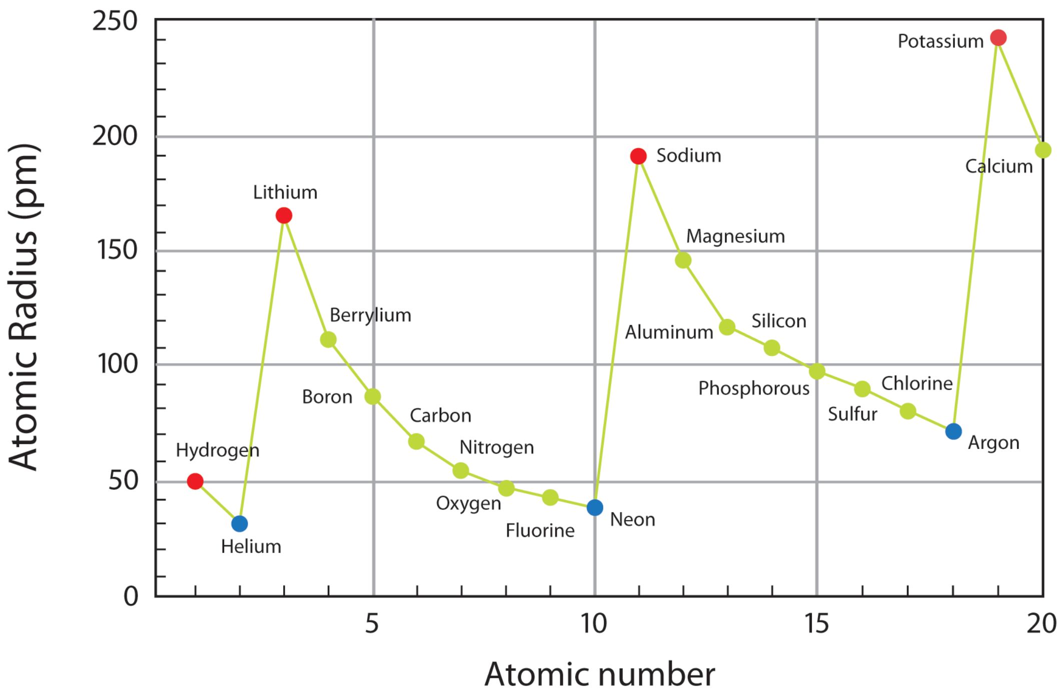
What is the significance of the word "periodic" in the periodic table of the elements? Because of the way the atoms are organized in the periodic table, a pattern of characteristics or properties that repeat "periodically" can be seen from row to row in the table. This is called *periodicity*. Hence, the "periodic" table.



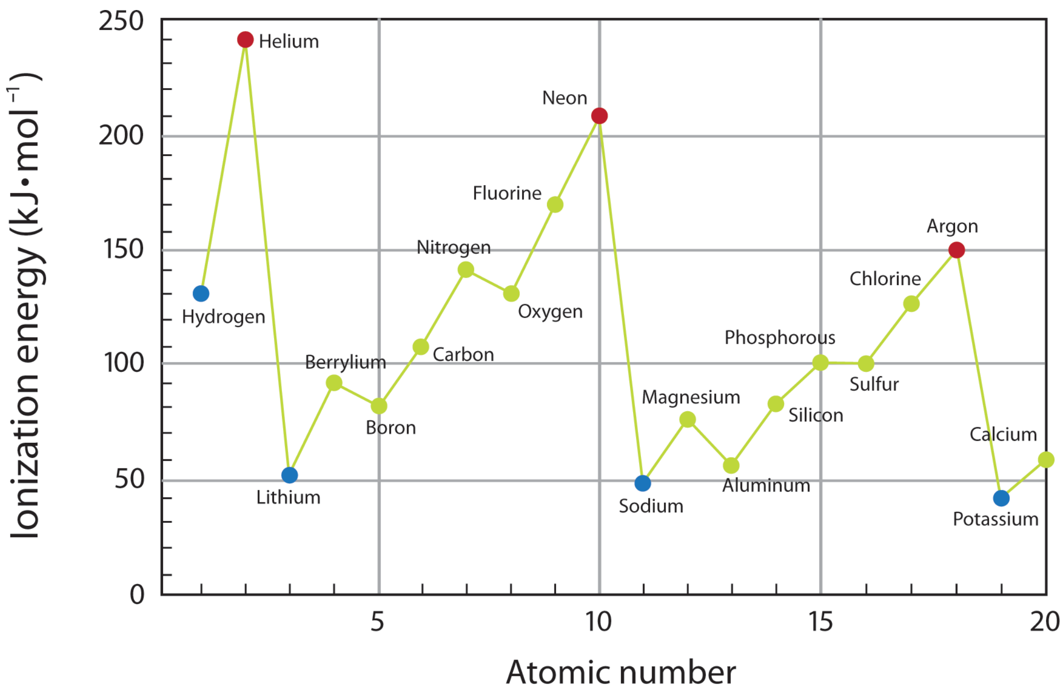


***Note**: Some charts of atomic radii show the atoms in the last column on the right (Helium, Neon, Argon …) having larger radii than one or more of the atoms to their left. This is a result of using a different measuring technique. For our purposes, the trend is decreasing atomic size as you move from left to right along a row.*

One property that demonstrates the idea of periodicity is atomic radius. Scientists measure atomic radii to tell them how large atoms are. As we proceed across a row (from left to right) we observe that atomic radii decrease. For example, magnesium has a smaller atomic radius than sodium, and aluminum has a smaller atomic radius than magnesium, and so on. This same pattern repeats itself in the next row and the next row in a periodic way.



Another example of periodicity is a property called *ionization energy*. Ionization energy refers to the amount of energy needed to remove an electron from an atom to form an ion. The more difficult it is to remove an electron from an atom, the higher its ionization energy. As a trend, ionization energy increases as you move across a row (from left to right). For example, in the first row, Hydrogen, on the far left, has a low ionization energy and Helium, on the far right, has a high ionization energy. Each row begins with a low value and ends with a high value.



This makes sense since the smaller the atom, the closer the valence electrons are to the nucleus. This closeness to the nucleus results in the electrons feeling a stronger attraction and requiring more energy to remove them.

