

Additional Teacher Background

Chapter 4 Lesson 3, p. 295

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.

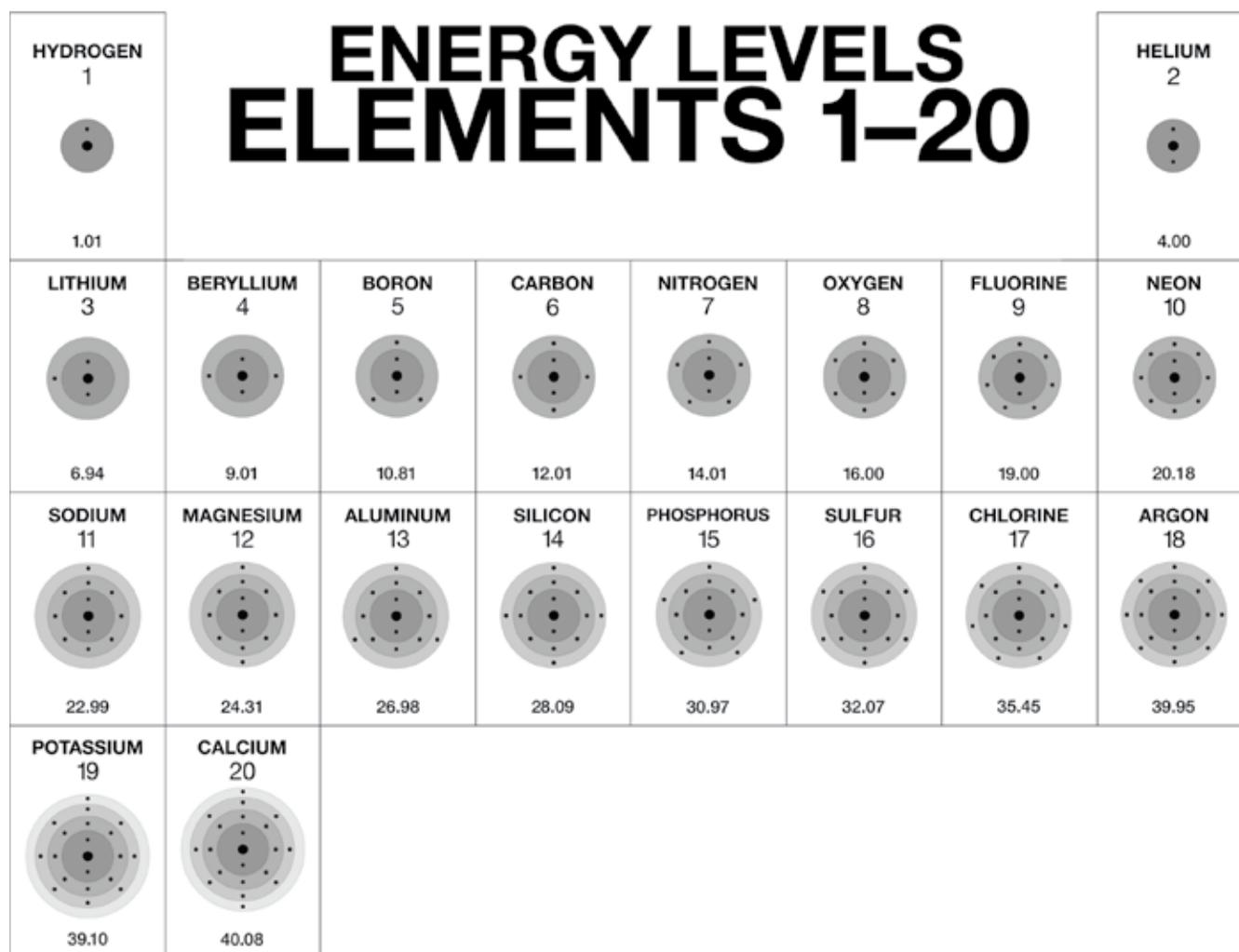
The Periodic Table of the Elements

1 H Hydrogen 1.01																	2 He Helium 4.00						
3 Li Lithium 6.94	4 Be Beryllium 9.01																	5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31																	13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80						
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29						
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)						
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium 178.49	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)													
			58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97							
			90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium 168.93	102 No Nobelium (259)	103 Lr Lawrencium (262)							

Legend for the periodic table:

- 3 — Atomic Number
- Li** — Element Symbol
- Lithium — Element Name
- 6.94 — Average Atomic Mass

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.

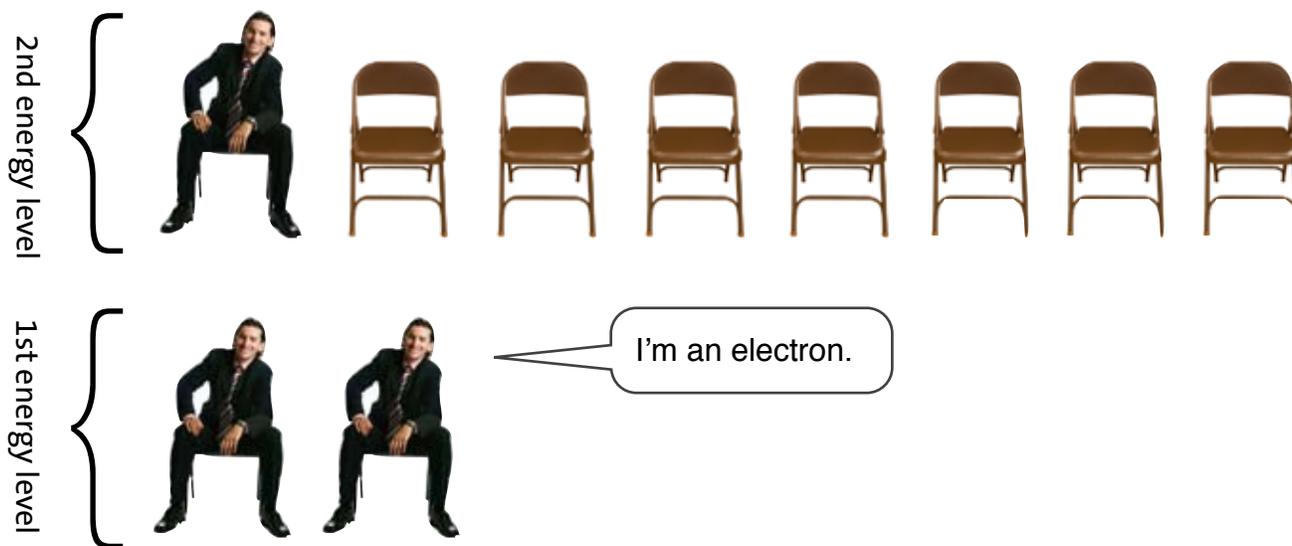
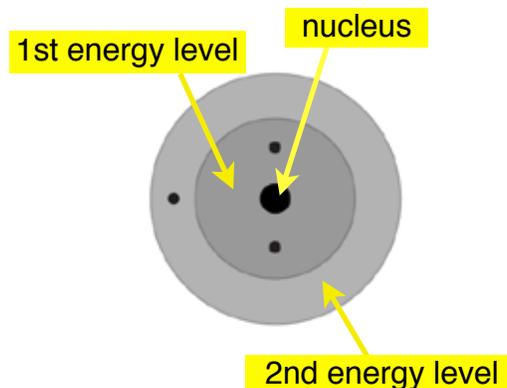
What do the rows represent?

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.



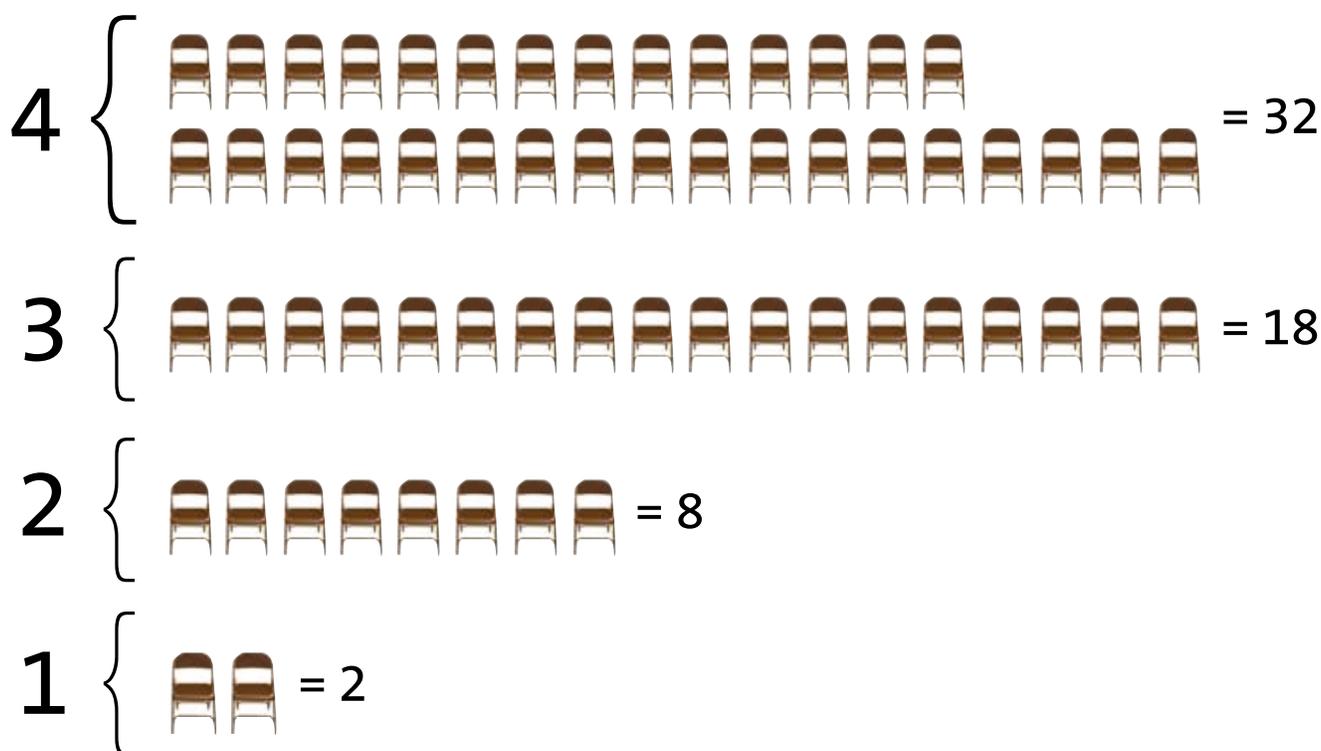
Not so bad, right? In general, this simple case is a helpful analogy. Electrons fill a given section until it is full, and then any more electrons move on to another unoccupied section where they continue filling there. Electrons begin filling the lowest energy level (closest to the nucleus) and then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

Energy Levels Can Hold Different Numbers of Electrons

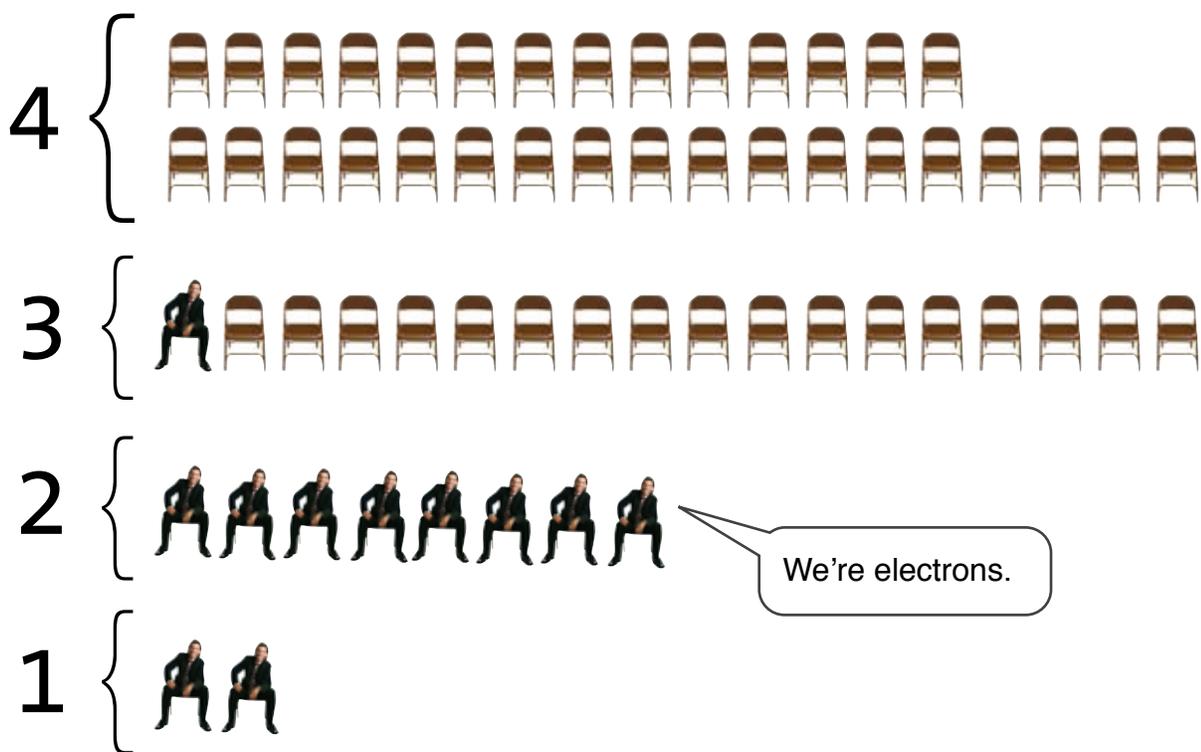
One thing that is slightly tricky about electrons filling these energy levels is that not all the energy levels can hold the same number of electrons. While the first energy level can hold only 2 electrons, the second energy level can hold 8, the third can hold 18, and the fourth can hold 32.

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.



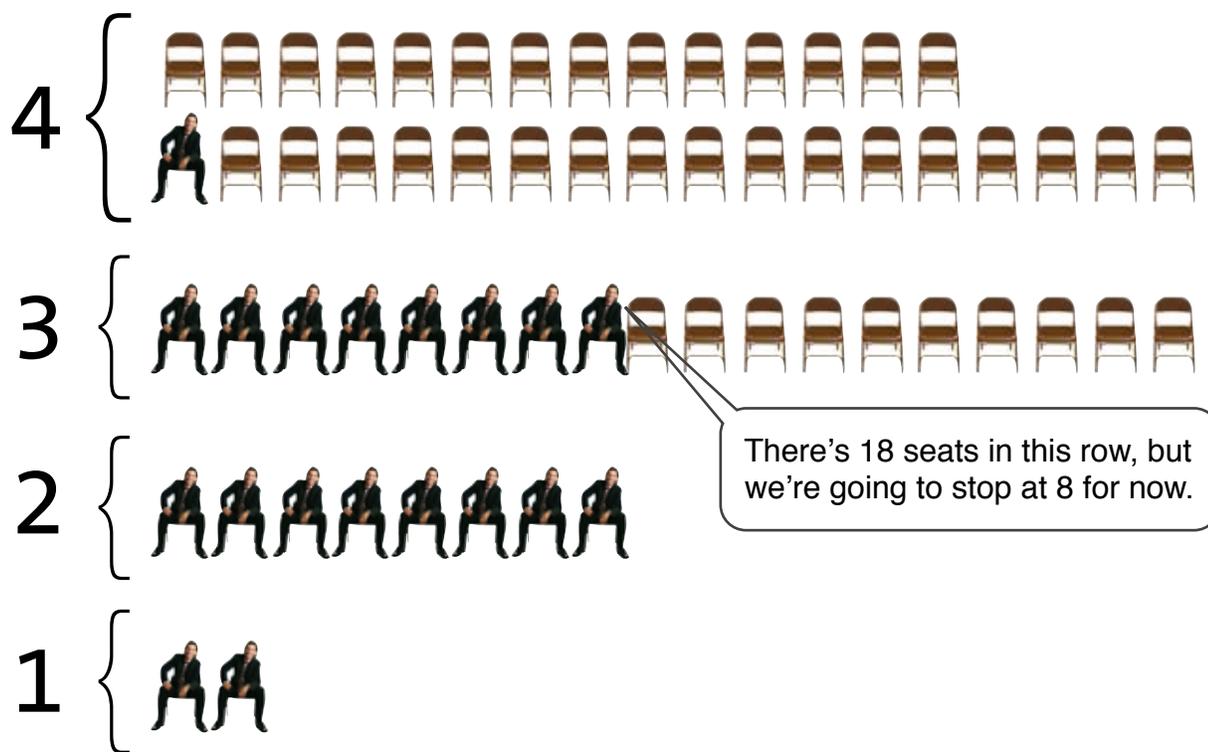
Extending our analogy of theater patrons as electrons, let's look at how the element sodium, with its 11 electrons, might fill these energy levels.



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:

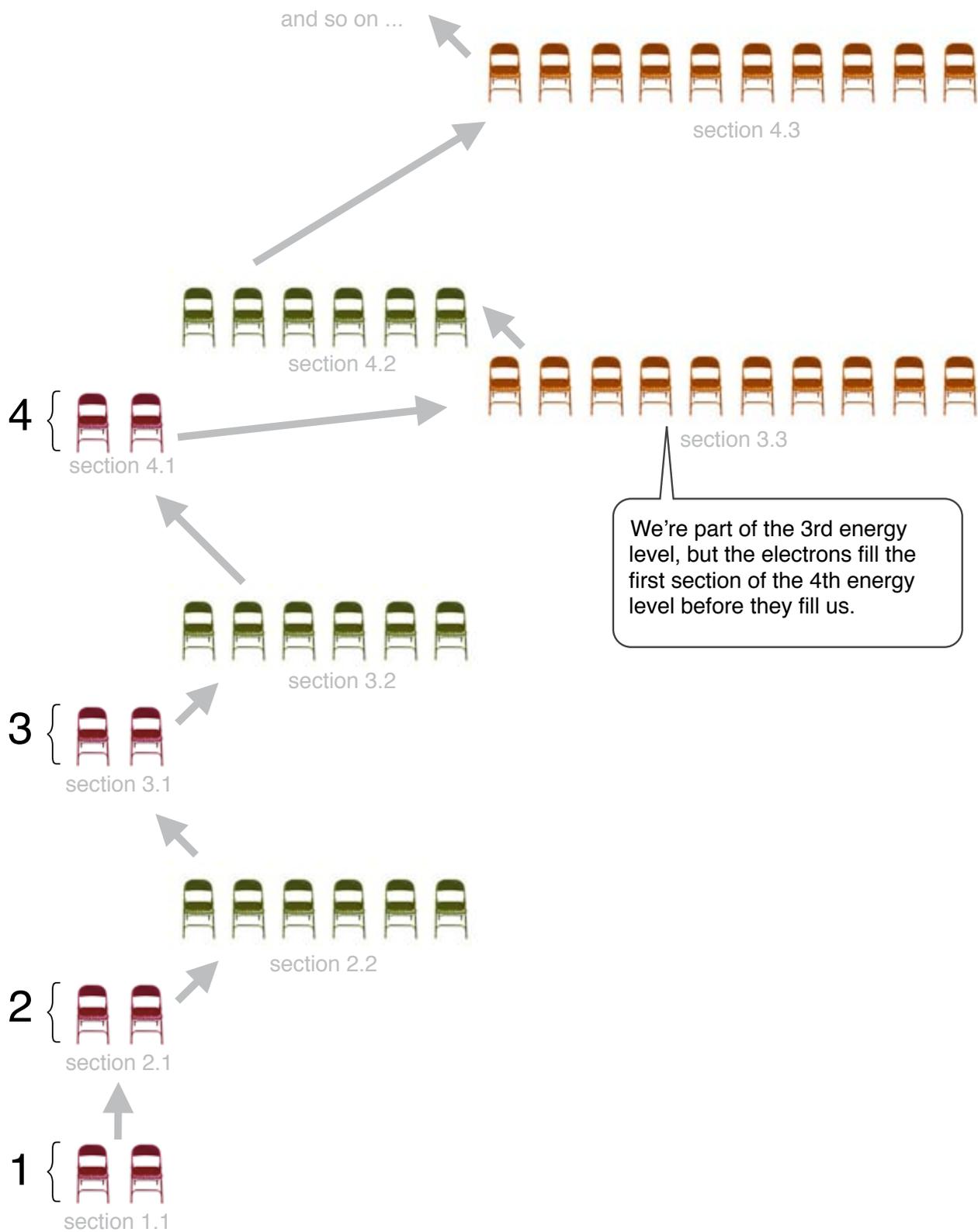


Whoa. *Whoa*. That's crazy. Why does *that* happen?

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.

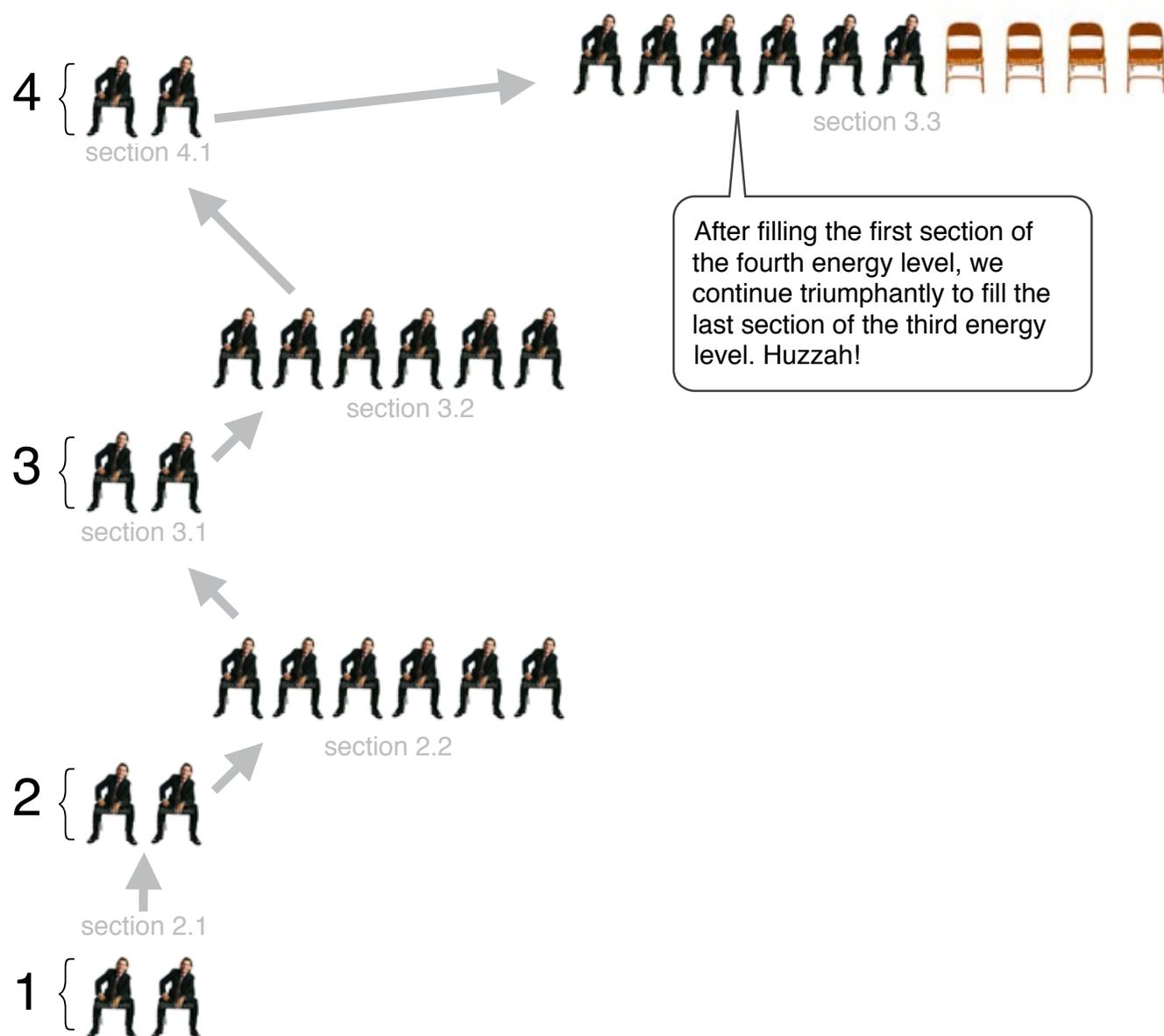
The reason why that last electron from potassium begins filling the fourth energy level rather than continuing to fill the third energy level is that the first section of the fourth energy level is actually closer (or at lower energy) than the last section of the third energy level (the last 10 "seats").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



Admittedly, this doesn't look much like rows of chairs 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.

The Periodic Table of the Elements

3	Li
Lithium	6.94

Atomic Number

Element Symbol

Element Name

Average Atomic Mass

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3 Li Lithium 6.94	4 Be Beryllium 9.01																	5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18								
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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.

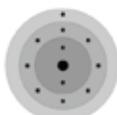
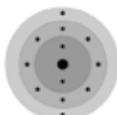
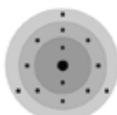
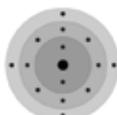
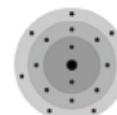
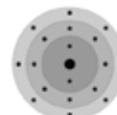
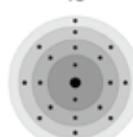
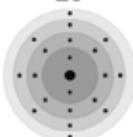
Although alternative forms of the periodic table have been created, some taking unusual shapes like a series of concentric circles in an archery target, the conventional table with the familiar groups and periods is considered the standard.

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.

ENERGY LEVELS ELEMENTS 1-20

<p>HYDROGEN 1</p>  <p>1.01</p>							<p>HELIUM 2</p>  <p>4.00</p>
<p>LITHIUM 3</p>  <p>6.94</p>	<p>BERYLLIUM 4</p>  <p>9.01</p>	<p>BORON 5</p>  <p>10.81</p>	<p>CARBON 6</p>  <p>12.01</p>	<p>NITROGEN 7</p>  <p>14.01</p>	<p>OXYGEN 8</p>  <p>16.00</p>	<p>FLUORINE 9</p>  <p>19.00</p>	<p>NEON 10</p>  <p>20.18</p>
<p>SODIUM 11</p>  <p>22.99</p>	<p>MAGNESIUM 12</p>  <p>24.31</p>	<p>ALUMINUM 13</p>  <p>26.98</p>	<p>SILICON 14</p>  <p>28.09</p>	<p>PHOSPHORUS 15</p>  <p>30.97</p>	<p>SULFUR 16</p>  <p>32.07</p>	<p>CHLORINE 17</p>  <p>35.45</p>	<p>ARGON 18</p>  <p>39.95</p>
<p>POTASSIUM 19</p>  <p>39.10</p>	<p>CALCIUM 20</p>  <p>40.08</p>						

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.

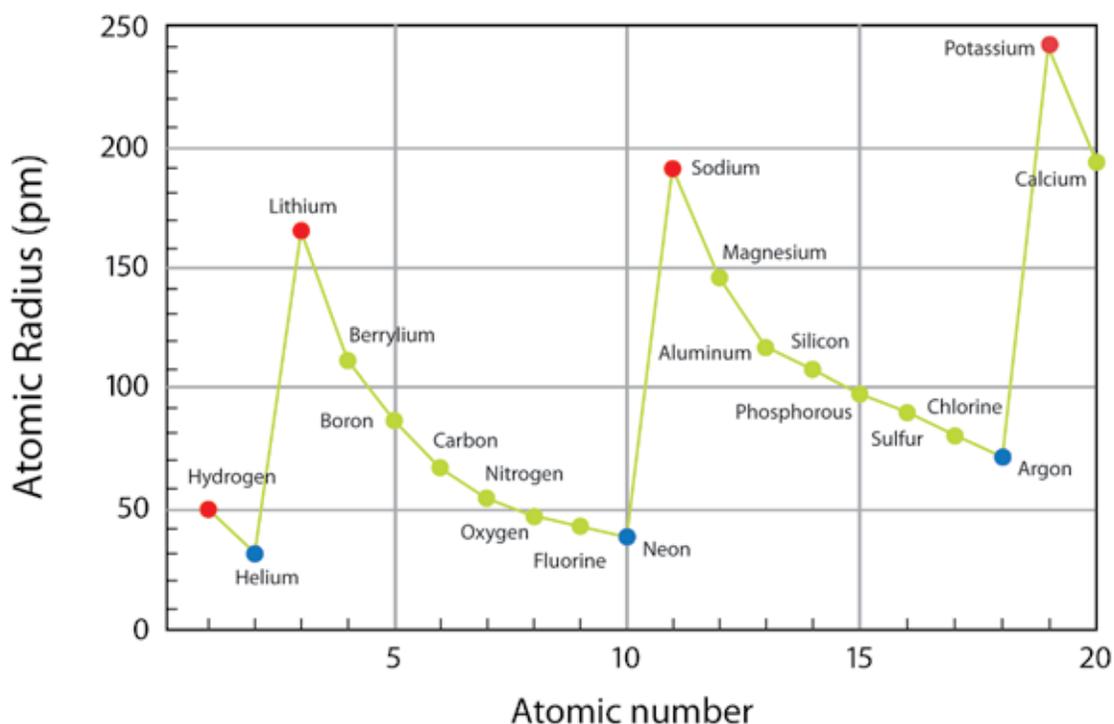
What is the significance of the word “periodic” in the periodic table of the elements?

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.

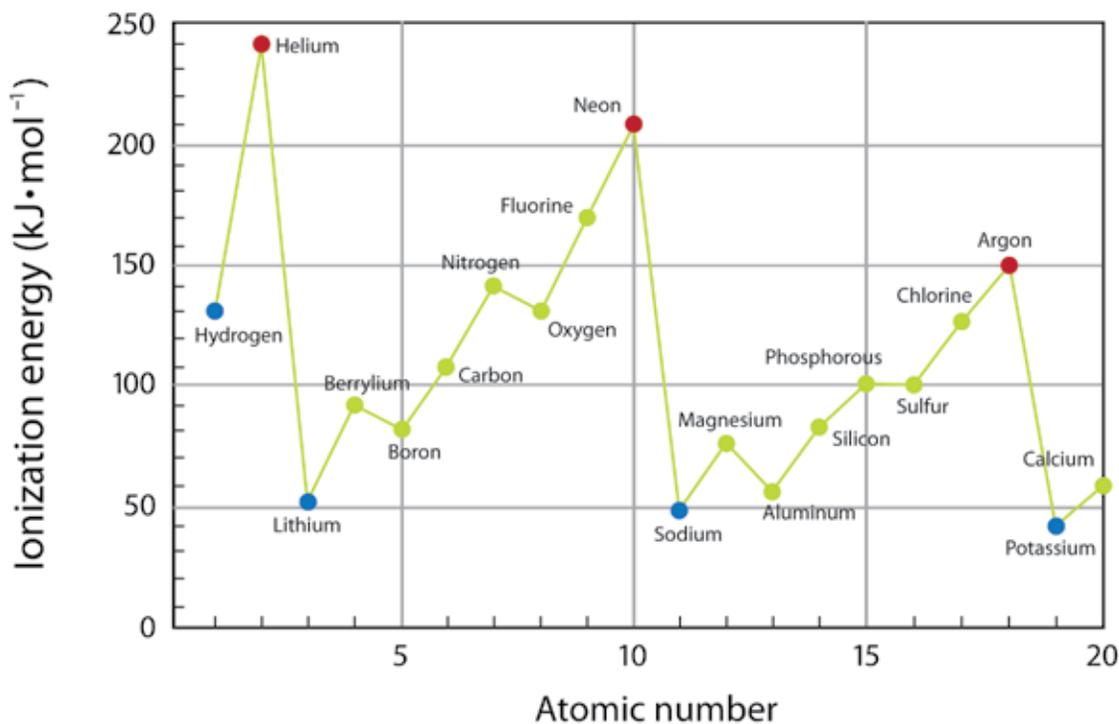
One property that demonstrates the idea of periodicity is atomic radius. Scientists measure atomic radii to tell them how large atoms are. As we proceed across a row (from left to right) we observe that atomic radii decrease. For example, magnesium has a smaller atomic radius than sodium, and aluminum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

<h1 style="text-align: center;">ATOMIC SIZE & MASS ELEMENTS 1-20</h1>							
HYDROGEN 1  1.01							HELIUM 2  4.00
LITHIUM 3  6.94	BERYLLIUM 4  9.01	BORON 5  10.81	CARBON 6  12.01	NITROGEN 7  14.01	OXYGEN 8  16.00	FLUORINE 9  19.00	NEON 10  20.18
SODIUM 11  22.99	MAGNESIUM 12  24.31	ALUMINUM 13  26.98	SILICON 14  28.09	PHOSPHORUS 15  30.97	SULFUR 16  32.07	CHLORINE 17  35.45	ARGON 18  39.95
POTASSIUM 19  39.10	CALCIUM 20  40.08						

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.



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.



There are other periodic trends in the properties of atoms. You can see some of these by going to <http://acswebcontent.acs.org/games/pt.html>.

Click the “Plot Data” tab to get to a drop-down menu of different properties you can choose. The first one displayed is “Molar Mass” which shows the mass of a mole of each atom. This can be thought of as comparing the atomic mass of one atom to another. This property is not periodic. You can choose atomic radius or ionization energy to see the trends discussed earlier or select another property.