

8.4 Electronic Structure and the Periodic Table

LEARNING OBJECTIVES

1. Relate the electron configurations of the elements to the shape of the periodic table.
2. Determine the expected electron configuration of an element by its place on the periodic table.

In [Chapter 3 "Atoms, Molecules, and Ions"](#), we introduced the periodic table as a tool for organizing the known chemical elements. A periodic table is shown in [Figure 8.8 "The Periodic Table"](#). The elements are listed by atomic number (the number of protons in the nucleus), and elements with similar chemical properties are grouped together in columns.

Figure 8.8 The Periodic Table

¹ H 1.00794	² He 4.002602
³ Li 6.941	⁴ Be 9.012182
¹¹ Na 22.989770	¹² Mg 24.3050
¹⁹ K 39.0983	²⁰ Ca 40.078
³⁷ Rb 85.4678	³⁸ Sr 87.62
⁵⁵ Cs 132.90545	⁵⁶ Ba 137.327
⁸⁷ Fr (223)	⁸⁸ Ra (226)
³ Li 6.941	⁴ Be 9.012182
¹¹ Na 22.989770	¹² Mg 24.3050
¹⁹ K 39.0983	²⁰ Ca 40.078
³⁷ Rb 85.4678	³⁸ Sr 87.62
⁵⁵ Cs 132.90545	⁵⁶ Ba 137.327
⁸⁷ Fr (223)	⁸⁸ Ra (226)
²¹ Sc 44.955910	²² Ti 47.867
⁴⁰ Zr 91.1224	⁴¹ Nb 92.90638
⁵⁵ Cs 132.90545	⁵⁷ La 138.9055
⁸⁷ Fr (223)	⁸⁹ Ac (227)
²¹ Sc 44.955910	²² Ti 47.867
⁴⁰ Zr 91.1224	⁴¹ Nb 92.90638
⁵⁵ Cs 132.90545	⁵⁷ La 138.9055
⁸⁷ Fr (223)	⁸⁹ Ac (227)
²³ V 50.9415	²⁴ Cr 51.9961
⁴¹ Nb 95.94	⁴² Mo (95.94)
⁵⁷ La 178.49	⁷² Hf 180.9479
⁸⁹ Ac (261)	¹⁰⁴ Rf (262)
²³ V 50.9415	²⁴ Cr 51.9961
⁴¹ Nb 95.94	⁴² Mo (95.94)
⁵⁷ La 178.49	⁷² Hf 180.9479
⁸⁹ Ac (261)	¹⁰⁴ Rf (262)
²⁵ Mn 54.938049	²⁶ Fe 55.845
⁴³ Tc (98)	⁴⁴ Ru 101.07
⁷⁵ Re 183.84	⁷⁶ Os 190.23
¹⁰⁶ Sg (263)	¹⁰⁷ Bh (262)
¹⁰⁶ Sg (263)	¹⁰⁸ Hs (265)
¹⁰⁷ Bh (262)	¹⁰⁹ Mt (266)
¹⁰⁸ Hs (265)	¹¹⁰ Mt (269)
¹⁰⁹ Mt (266)	¹¹¹ Mt (272)
¹¹⁰ Mt (269)	¹¹² Mt (277)
¹¹¹ Mt (272)	¹¹² Mt (277)
⁵ B 10.811	⁶ C 12.0107
¹³ Al 26.581538	¹⁴ Si 30.973761
¹⁵ P 32.066	¹⁶ S 35.4527
¹⁷ Cl 39.948	¹⁸ Ne 20.1797
³² Ge 72.61	³³ As 74.92160
³⁴ Se 78.96	³⁵ Br 79.504
³⁶ Kr 83.80	³⁷ Kr 131.29
⁵² Te 127.60	⁵³ I 126.90447
⁵⁴ Xe 131.29	⁵⁵ Te 127.60
⁸² Bi (209)	⁸⁴ Po (209)
⁸³ Bi (209)	⁸⁵ At (210)
⁸⁶ Rn (222)	⁸⁶ Rn (222)

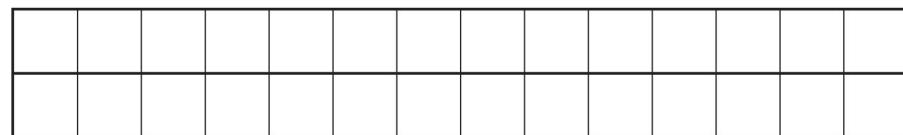
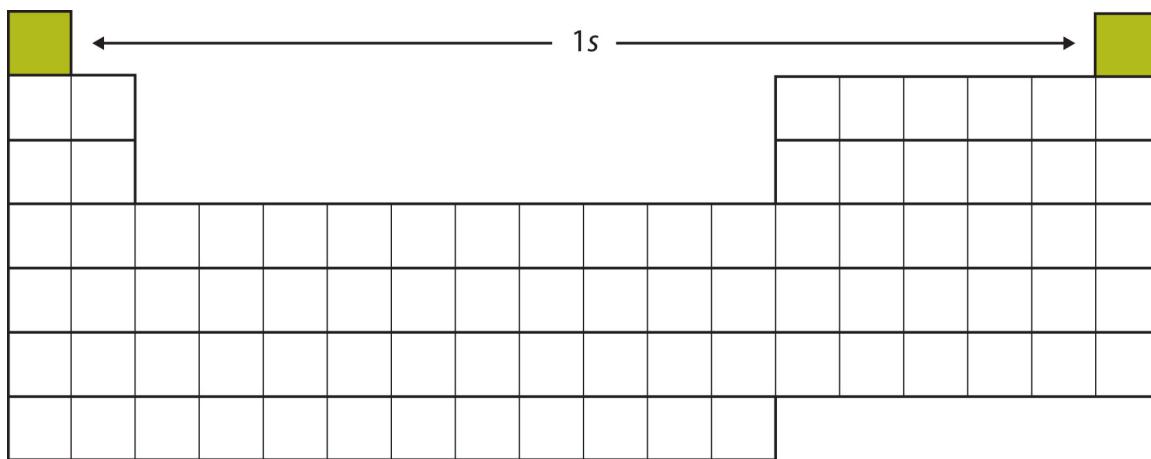
58 Ce 140.116	59 Pr 140.50765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa 231.03588	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Md (257)	101 Md (258)	102 No (259)	103 Lr (262)

Why does the periodic table have the structure it does? The answer is rather simple, if you understand electron configurations: *the shape of the periodic table mimics the filling of the subshells with electrons.*

Let us start with H and He. Their electron configurations are $1s^1$ and $1s^2$, respectively; with He, the $n = 1$ shell is filled. These two elements make up the first row of the periodic table (see [Figure 8.9 "The 1"](#)).

Figure 8.9 The 1s Subshell

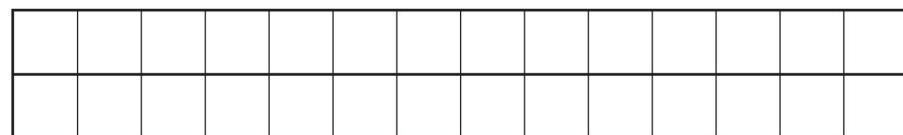
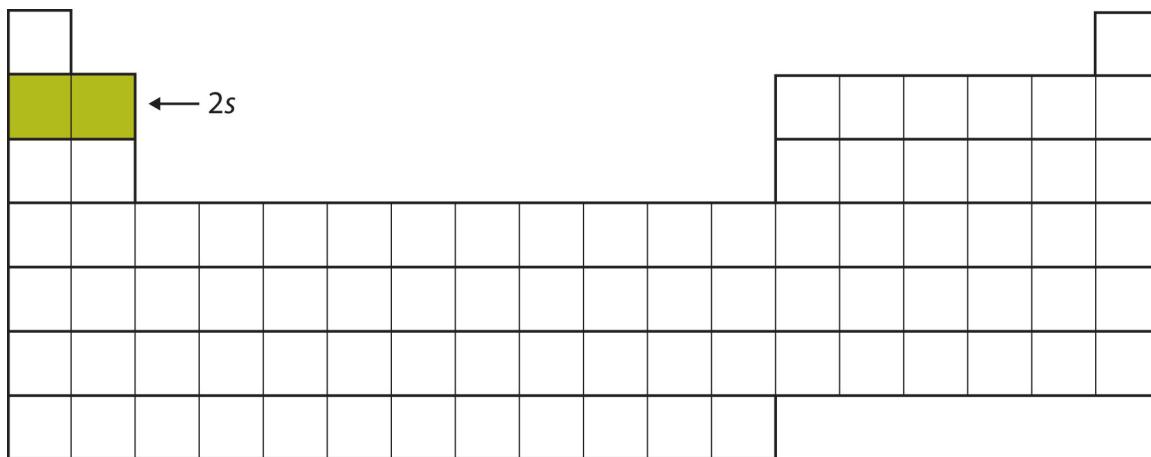




H and He represent the filling of the 1s subshell.

The next two electrons, for Li and Be, would go into the 2s subshell. [Figure 8.10 "The 2s"](#) shows that these two elements are adjacent on the periodic table.

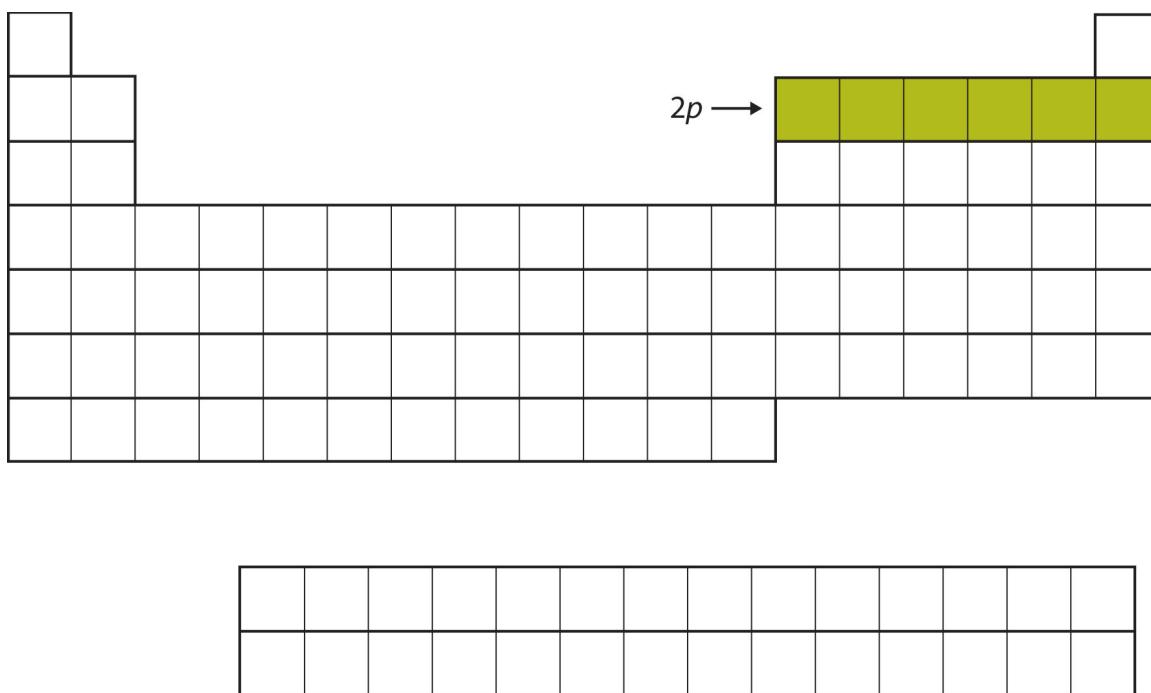
Figure 8.10 The 2s Subshell



In Li and Be, the 2s subshell is being filled.

For the next six elements, the $2p$ subshell is being occupied with electrons. On the right side of the periodic table, these six elements (B through Ne) are grouped together ([Figure 8.11 "The 2"](#)).

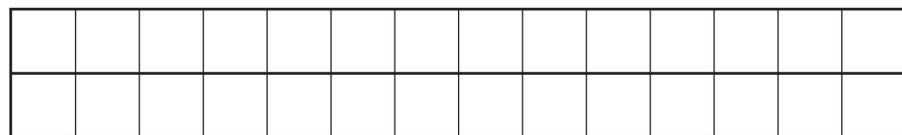
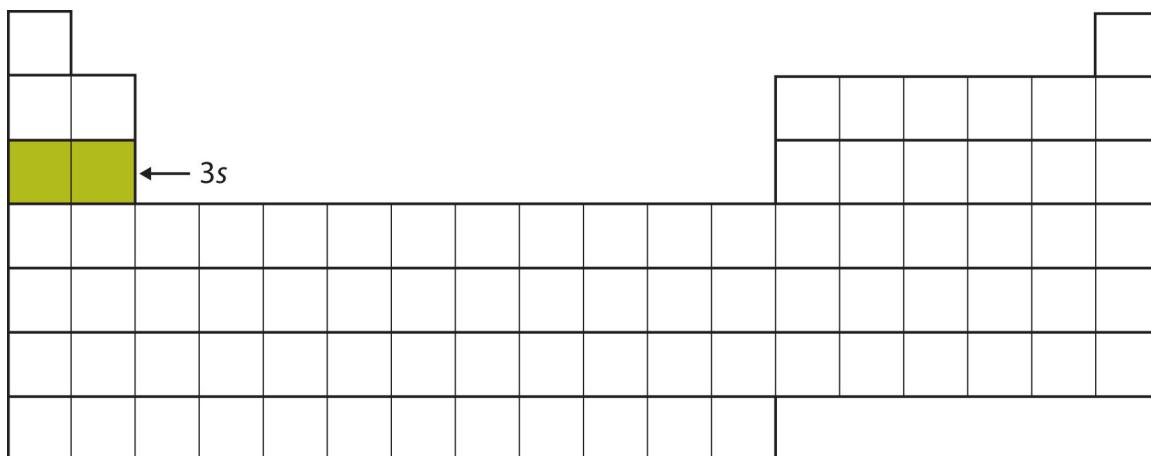
Figure 8.11 The 2p Subshell



For B through Ne, the $2p$ subshell is being occupied.

The next subshell to be filled is the $3s$ subshell. The elements when this subshell is being filled, Na and Mg, are back on the left side of the periodic table ([Figure 8.12 "The 3"](#)).

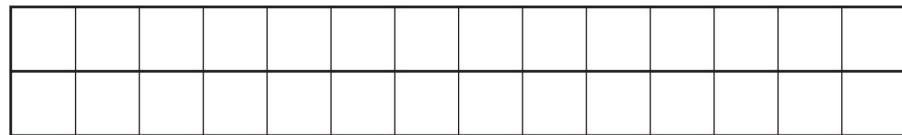
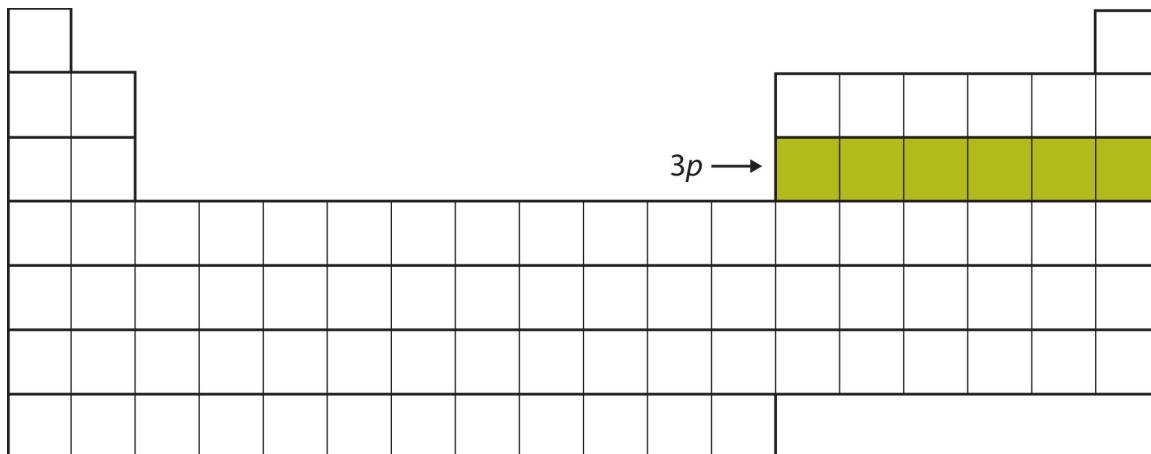
Figure 8.12 The 3s Subshell



Now the 3s subshell is being occupied.

Next, the 3p subshell is filled with the next six elements (Figure 8.13 "The 3").

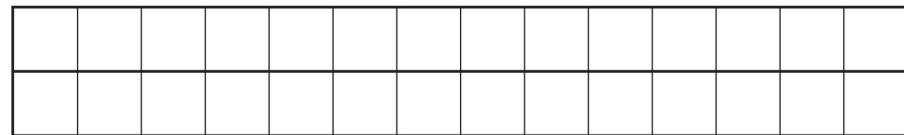
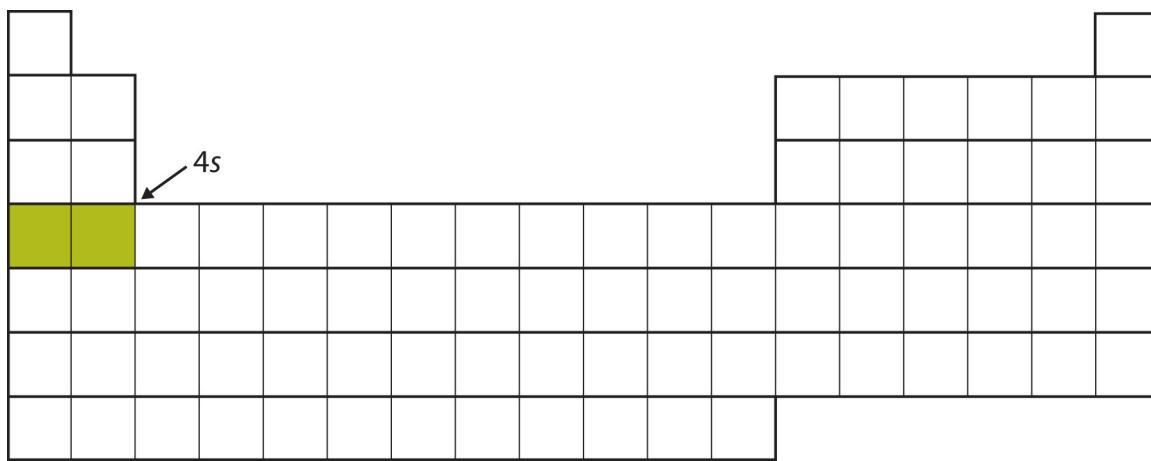
Figure 8.13 The 3p Subshell



Next, the 3p subshell is filled with electrons.

Instead of filling the $3d$ subshell next, electrons go into the $4s$ subshell ([Figure 8.14 "The 4"](#)).

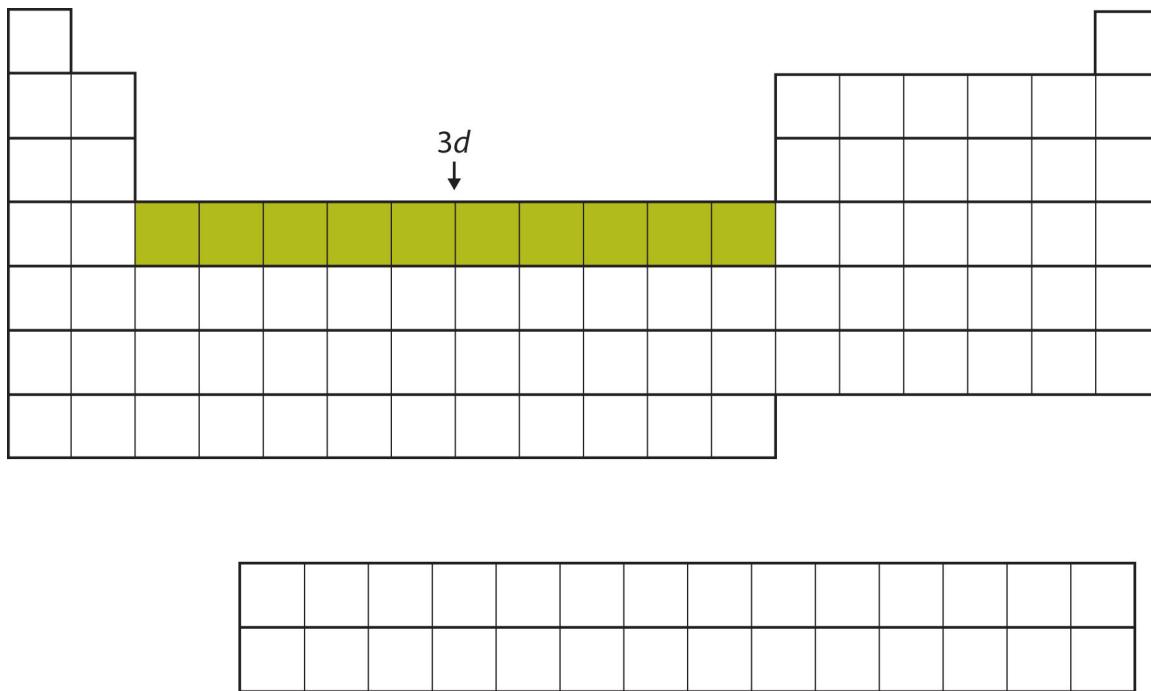
Figure 8.14 The 4s Subshell



The $4s$ subshell is filled before the $3d$ subshell. This is reflected in the structure of the periodic table.

After the $4s$ subshell is filled, the $3d$ subshell is filled with up to 10 electrons. This explains the section of 10 elements in the middle of the periodic table ([Figure 8.15 "The 3"](#)).

Figure 8.15 The 3d Subshell



The 3d subshell is filled in the middle section of the periodic table.

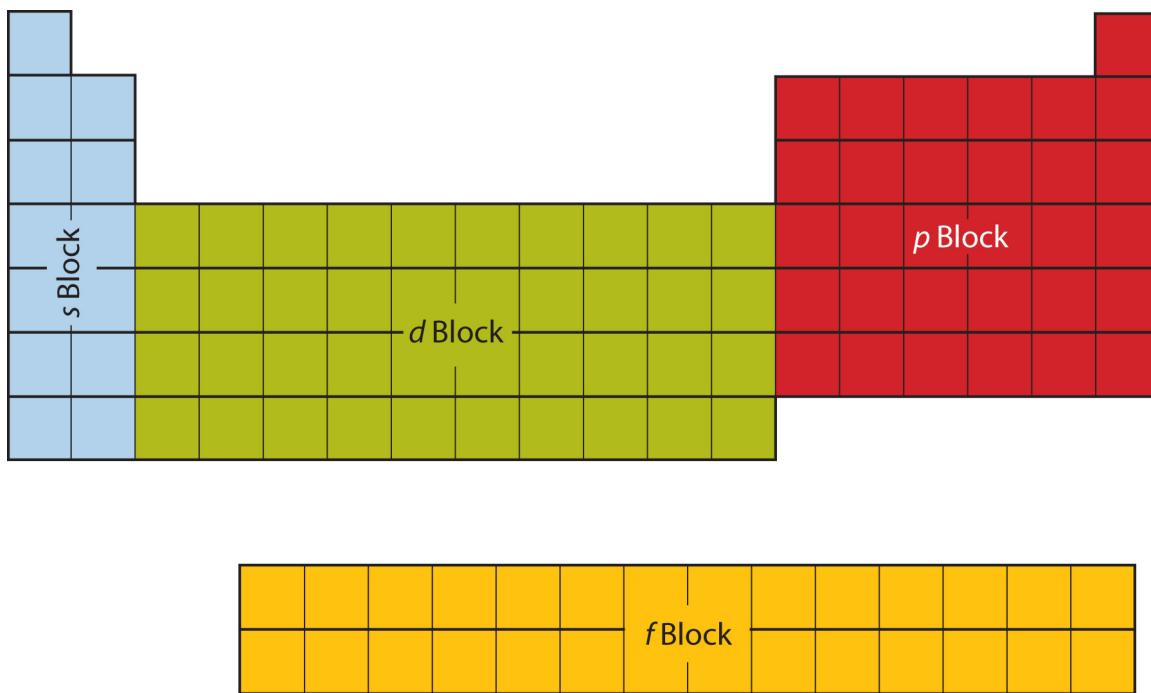
And so forth. As we go across the rows of the periodic table, the overall shape of the table outlines how the electrons are occupying the shells and subshells.

The first two columns on the left side of the periodic table are where the s subshells are being occupied. Because of this, the first two rows of the periodic table are labeled the *s block*. Similarly, the *p block* are the right-most six columns of the periodic table,

the *d block* is the middle 10 columns of the periodic table, while

the *f block* is the 14-column section that is normally depicted as detached from the main body of the periodic table. It could be part of the main body, but then the periodic table would be rather long and cumbersome. [Figure 8.16 "Blocks on the Periodic Table"](#) shows the blocks of the periodic table.

Figure 8.16 Blocks on the Periodic Table



The periodic table is separated into blocks depending on which subshell is being filled for the atoms that belong in that section.

The electrons in the highest-numbered shell, plus any electrons in the last unfilled subshell, are called valence electrons; the highest-numbered shell is called the valence shell. (The inner electrons are called *core electrons*.) The valence electrons largely control the chemistry of an atom. If we look at just the valence shell's electron configuration, we find that in each column, the valence shell's electron configuration is the same. For example, take the elements in the first column of the periodic table: H, Li, Na, K, Rb, and Cs. Their electron configurations (abbreviated for the larger atoms) are as follows, with the valence shell electron configuration highlighted:

H:	$1s^1$
Li:	$1s^2 2s^1$
Na:	$[\text{Ne}]3s^1$
K:	$[\text{Ar}]4s^1$

Rb:	$[\text{Kr}]5s^1$
Cs:	$[\text{Xe}]6s^1$

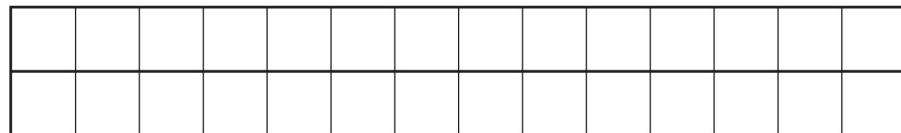
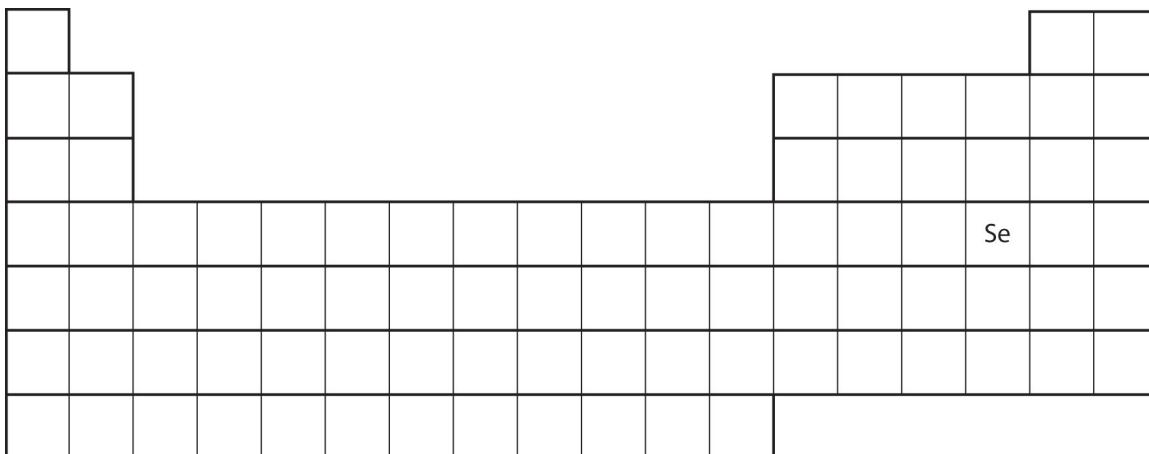
They all have a similar electron configuration in their valence shells: a single s electron. Because much of the chemistry of an element is influenced by valence electrons, we would expect that these elements would have similar chemistry—*and they do*. The organization of electrons in atoms explains not only the shape of the periodic table but also the fact that elements in the same column of the periodic table have similar chemistry.

The same concept applies to the other columns of the periodic table. Elements in each column have the same valence shell electron configurations, and the elements have some similar chemical properties. This is strictly true for all elements in the s and p blocks. In the d and f blocks, because there are exceptions to the order of filling of subshells with electrons, similar valence shells are not absolute in these blocks. However, many similarities do exist in these blocks, so a similarity in chemical properties is expected.

Similarity of valence shell electron configuration implies that we can determine the electron configuration of an atom solely by its position on the periodic table.

Consider Se, as shown in [Figure 8.17 "Selenium on the Periodic Table"](#). It is in the fourth column of the p block. This means that its electron configuration should end in a p^4 electron configuration. Indeed, the electron configuration of Se is $[\text{Ar}]4s^23d^{10}4p^4$, as expected.

Figure 8.17 Selenium on the Periodic Table



EXAMPLE 8

From the element's position on the periodic table, predict the valence shell electron configuration for each atom. See [Figure 8.18 "Various Elements on the Periodic Table"](#).

1. Ca
2. Sn

Solution

1. Ca is located in the second column of the *s* block. We would expect that its electron configuration should end with s^2 . Calcium's electron configuration is $[\text{Ar}]4s^2$.
2. Sn is located in the second column of the *p* block, so we expect that its electron configuration would end in p^2 . Tin's electron configuration is $[\text{Kr}]5s^24d^{10}5p^2$.

Test Yourself

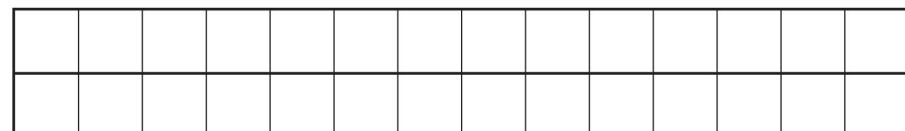
From the element's position on the periodic table, predict the valence shell electron configuration for each atom. See [Figure 8.18 "Various Elements on the Periodic Table"](#).

1. Ti
2. Cl

Answer

1. $[\text{Ar}]4s^23d^2$
2. $[\text{Ne}]3s^23p^5$

Figure 8.18 Various Elements on the Periodic Table



Food and Drink App: Artificial Colors

The color of objects comes from a different mechanism than the colors of neon and other discharge lights. Although colored lights produce their colors, objects are colored because they preferentially reflect a certain color from the white light that shines on them. A red tomato, for example, is bright red because it reflects red light while absorbing all the other colors of the rainbow.

Many foods, such as tomatoes, are highly colored; in fact, the common statement “you eat with your eyes first” is an implicit recognition that the visual appeal of food is just as important as its taste. But what about processed foods?

Many processed foods have food colorings added to them. There are two types of food colorings: natural and artificial. Natural food colorings include caramelized sugar for brown; annatto, turmeric, and saffron for various shades of orange or yellow; betanin from beets for purple; and even carmine, a deep red dye that is extracted from the cochineal, a small insect that is a parasite on cacti in Central and South America. (That's right: you may be eating bug juice!)

Some colorings are artificial. In the United States, the Food and Drug Administration currently approves only seven compounds as artificial colorings in food, beverages, and cosmetics:

FD&C Blue #1: Brilliant Blue FCF

FD&C Blue #2: Indigotine

FD&C Green #3: Fast Green FCF

RD&C Red #3: Erythrosine

FD&C Red #40: Allura Red AC

FD&C Yellow #5: Tartrazine

FD&C Yellow #6: Sunset Yellow FCF

Lower-numbered colors are no longer on the market or have been removed for various reasons. Typically, these artificial colorings are large molecules that absorb certain colors of light very strongly, making them useful even at very low concentrations in foods and cosmetics. Even at such low amounts, some critics claim that a small portion of the population (especially children) is sensitive to artificial colorings and urge that their use be curtailed or halted. However, formal studies of artificial colorings and their effects on behavior have been inconclusive or contradictory. Despite this, most people continue to enjoy processed foods with artificial coloring (like those shown in the accompanying figure).



Artificial food colorings are found in a variety of food products, such as processed foods, candies, and egg dyes. Even pet foods have artificial food coloring in them, although it's likely that the animal doesn't care!

Source: Photo courtesy of Matthew

Bland, <http://www.flickr.com/photos/matthewbland/3111904731>.

KEY TAKEAWAYS

- The arrangement of electrons in atoms is responsible for the shape of the periodic table.
- Electron configurations can be predicted by the position of an atom on the periodic table.

EXERCISES

1. Where on the periodic table are *s* subshells being occupied by electrons?
2. Where on the periodic table are *d* subshells being occupied by electrons?
3. In what block is Ra found?
4. In what block is Br found?
5. What are the valence shell electron configurations of the elements in the second column of the periodic table?
6. What are the valence shell electron configurations of the elements in the next-to-last column of the periodic table?
7. What are the valence shell electron configurations of the elements in the first column of the *p* block?
8. What are the valence shell electron configurations of the elements in the last column of the *p* block?

9. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. Sr
- b. S

10. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. Fe
- b. Ba

11. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. V
- b. Ar

12. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. Cl
- b. K

13. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. Ge
- b. C



14. From the element's position on the periodic table, predict the electron configuration of each atom.

- a. Mg
- b. I

ANSWERS

1. the first two columns

3. the *s* block

5. ns^2

7. ns^2np^1

9. a. $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^2$

b. $1s^22s^22p^63s^23p^4$

11. a. $1s^22s^22p^63s^23p^64s^23d^3$

b. $1s^22s^22p^63s^23p^6$

13. a. $1s^22s^22p^63s^23p^64s^23d^{10}4p^2$

b. $1s^22s^22p^2$

