Solve Ionization energy increases as we move left to right across a period and decreases as we move down a group. Because Na, P, and Ar are in the same period, we expect I_1 to vary in the order Na < P < Ar. Because Ne is above Ar in group 8A, we expect Ar < Ne. Similarly, K is directly below Na in group 1A, and so we expect K < Na.

From these observations, we conclude that the ionization energies follow the order

$$K < Na < P < Ar < Ne$$

Check The values shown in Figure 7.9 confirm this prediction.

PRACTICE EXERCISE

Which has the lowest first ionization energy, B, Al, C, or Si? Which has the highest?

Answer: Al lowest, C highest

Electron Configurations of Ions

When electrons are removed from an atom to form a cation, they are always removed first from the occupied orbitals having the largest principal quantum number, n. For example, when one electron is removed from a lithium atom ($1s^2 2s^1$), it is the $2s^1$ electron:

$$Li\ (1s^2 2s^1) \Rightarrow Li^+\ (1s^2) + e^-$$

Likewise, when two electrons are removed from Fe ($[Ar]3d^6 4s^2$), the $4s^2$ electrons are the ones removed:

$$Fe\ ([Ar]3d^6 4s^2) \Rightarrow Fe^{2+}\ ([Ar]3d^6) + 2e^-$$

If an additional electron is removed, forming Fe^{3+}, it comes from a $3d$ orbital because all the orbitals with $n = 4$ are empty:

$$Fe^{2+}\ ([Ar]3d^6) \Rightarrow Fe^{3+}\ ([Ar]3d^5) + e^-$$

It may seem odd that $4s$ electrons are removed before $3d$ electrons in forming transition-metal cations. After all, in writing electron configurations, we added the $4s$ electrons before the $3d$ ones. In writing electron configurations for atoms, however, we are going through an imaginary process in which we move through the periodic table from one element to another. In doing so, we are adding both an electron to an orbital and a proton to the nucleus to change the identity of the element. In ionization, we do not reverse this process because no protons are being removed.

If there is more than one occupied subshell for a given value of n, the electrons are first removed from the orbital with the highest value of l. For example, a tin atom loses its $5p$ electrons before it loses its $5s$ electrons:

$$Sn\ ([Kr]4d^{10}5s^2 5p^2) \Rightarrow Sn^{2+}\ ([Kr]4d^{10}5s^2) + 2e^- \Rightarrow Sn^{4+}\ ([Kr]4d^{10}) + 4e^-$$

Electrons added to an atom to form an anion are added to the empty or partially filled orbital having the lowest value of n. For example, an electron added to a fluorine atom to form the F^- ion goes into the one remaining vacancy in the $2p$ subshell:

$$F\ (1s^2 2s^2 2p^5) + e^- \Rightarrow F^-\ (1s^2 2s^2 2p^6)$$

GIVE IT SOME THOUGHT

Do Cr^{3+} and V^{2+} have the same or different electron configurations?

SAMPLE EXERCISE 7.7 Electron Configurations of Ions

Write the electron configuration for **(a)** Ca^{2+}, **(b)** Co^{3+}, and **(c)** S^{2-}.

SOLUTION

Analyze and Plan We are asked to write electron configurations for three ions. To do so, we first write the electron configuration of each parent atom, then remove or add electrons to form the ions. Electrons are first removed from the orbitals having the highest value of n. They are added to the empty or partially filled orbitals having the lowest value of n.