SECTION 1.2

The Periodic Table

Key Terms

periodic law
period
group

The periodic table contains a large amount of useful data. For example, you can use the periodic table to look up chemical symbols, atomic numbers, and average atomic masses of elements. However, the periodic table can reveal much more about the elements when you have a full understanding of its design.

The Development of the Periodic Table

During a timespan of about 200 years, between the 1600s and the 1800s, chemists increased the number of recognized elements to 63 and observed and recorded many of their properties. Chemists began to observe similarities in the chemical nature of groups of elements. English chemist John Newlands (1837–1898) discovered that 56 elements could be classified into 11 groups that have similar chemical properties. Newlands also discovered that the elements in each group differed in atomic mass (then called atomic weight) by factors of eight.

Working independently of each other, German chemist Lothar Meyer (1830–1895) and Russian chemist Dmitri Mendeleev (1834–1907) both developed a table of the known elements according to their atomic masses. Because Mendeleev published his table first (1869), he is considered to be the "father" of the periodic table.

To develop his table, Mendeleev made a card for each of the 63 known elements. He wrote the symbol, atomic mass, and chemical and physical properties of an element on each card. Mendeleev arranged the 63 cards vertically, according to the atomic masses of the elements. When he came to an element that had chemical and physical characteristics that were similar to the first element in the previous column, he started a new column. He then placed the next element beside the element with similar properties. In a few cases, however, Mendeleev had to reverse the order of the elements to make their chemical properties match those of their neighbouring elements. Later, in 1913, British physicist Henry Moseley (1887–1915) developed a method for determining the number of protons in the nucleus of atoms, and thus the atomic number of an element. When the elements were ordered according to atomic number instead of atomic mass, the order agreed with Mendeleev's order.

Mendeleev left several gaps in his periodic table, attributing these gaps to elements that had not yet been discovered. The positions of these gaps enabled him to predict the properties of the missing elements. Several of these elements were discovered within the next few years, and the properties that Mendeleev had predicted were shown to be correct. The discovery of these elements gave validity to Mendeleev's work. The first periodic table that Mendeleev published is shown in **Figure 1.10**.

Figure 1.10 In Mendeleev's first periodic table, he listed the atomic masses vertically and placed elements with similar properties in horizontal rows.

Infer *why some of the columns are longer than others.*

Characteristics of the Modern Periodic Table

The periodic table that you use today looks very different from Mendeleev's table, but it is based on the same periodic, or repeating, relationships. In fact, chemists now call the concept underlying the organization of the periodic table the **periodic law**.

periodic law a statement that describes the repeating nature of the properties of the elements

> **The Periodic Law**
> When elements are arranged by atomic number, their chemical and physical properties recur periodically.

Modern chemists have learned much more about the properties of elements and have filled in all the gaps in Mendeleev's table. As you read in Section 1.1, chemists have also learned much more about the structure of atoms in general. This new information can explain the periodic nature of the table. To begin to understand the periodicity, examine the partial periodic table in **Figure 1.11**. Only the atomic numbers and Lewis diagrams of the elements are shown in the table. The Lewis diagrams clearly show the configuration of the electrons in the valence shell of the atoms of each element.

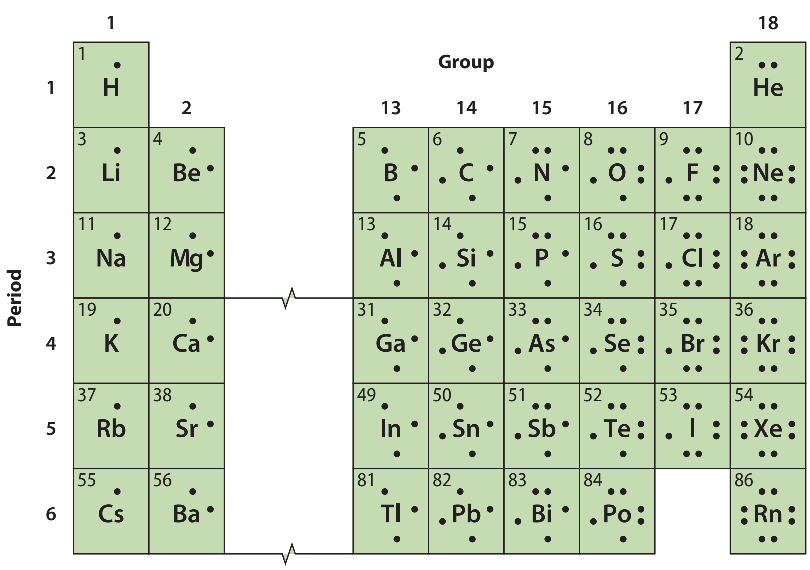


Figure 1.11 Lewis diagrams are shown in this partial periodic table, so you can quickly and easily analyze the electron configuration in each column of the table.

The atomic number increases as you go from left to right in the table. Because the atomic number is the number of protons in the nucleus of an atom, the number of electrons must also increase to make the net charge on the atom zero. The rows are called **periods**. The period number is the number of electron shells that are occupied by one or more electrons. As you go across a period, the outer electron shell is being filled. When the shell contains the maximum number of electrons allowed in that shell, the period ends. Because the first shell can contain only two electrons, the first period has only two elements. The second shell can contain up to eight electrons, so the second period has eight elements. The partial periodic table in **Figure 1.11** omits columns 3 through 12 because, in Period 4, the valence shells of atoms of some elements have more than eight electrons. The analysis of the electron structure of these elements is very complex, so it is left for more advanced chemistry courses.

period a row in the periodic table

group a column in the periodic table

Figure 1.11 was drawn with only valence electrons to highlight another important feature of the elements as they are arranged in the periodic table. The columns are called **groups**. All elements in a group have the same electron configuration in the valence shell of their atoms. Before chemists knew about valence electrons, they knew that the elements in each group had similar chemical and physical properties. Chemists now know that the configuration of the valence electrons is responsible for these similar properties.

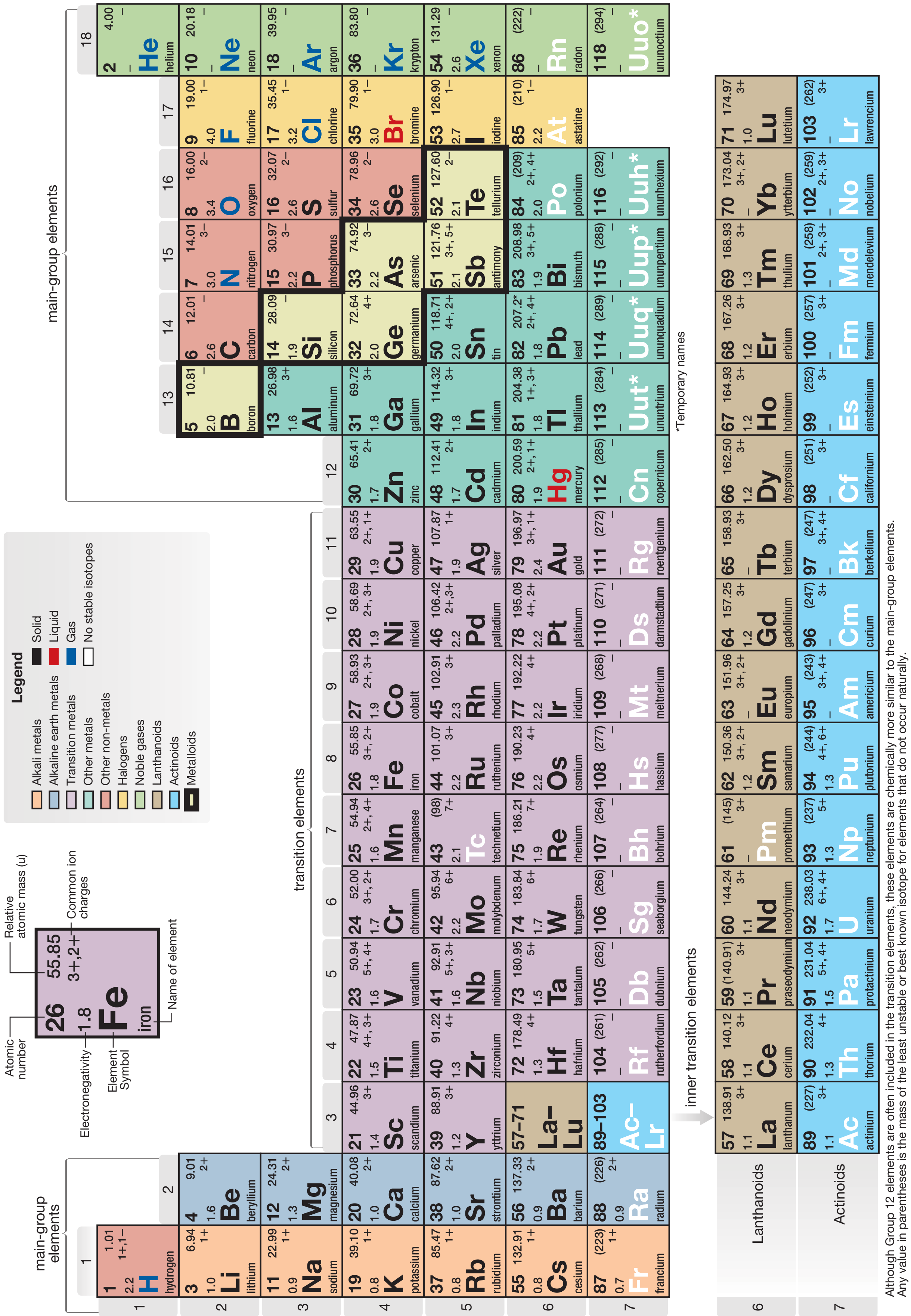


Figure 1.12 The brackets above this table divide the elements into large general categories, while the colours break down the categories according to the chemical properties of the elements.

Categories within the Complete Periodic Table

So far, you have been examining a partial periodic table. The design of the complete, modern, periodic table makes it possible to divide the elements into categories based on their properties. The complete periodic table in **Figure 1.12** has brackets and colour codes that highlight different categories of elements.

Categorizing Elements According to Their Properties

The colours codes in **Figure 1.12** divide the elements into categories that highlight unique chemical and physical properties. Some of the categories have specific names. **Figure 1.13** shows a reduced copy of the periodic table in **Figure 1.12**, with labels that show the names of these categories. You will see references to these categories many times throughout your study of chemistry.

Suggested Investigation

Inquiry Investigation 1-A, Developing an Activity Series

alkali metals All of the elements in Group 1, except hydrogen, are called alkali metals. They are very reactive. In fact, all alkali metals react vigorously with water. When rubidium and cesium are added to water, the reaction with water is explosive.

other non-metals This category consists of the non-metals that are not halogens or noble gases. These non-metals are neither as reactive as the halogens nor as unreactive as the noble gases. They are the most common elements in the tissues of living organisms.

noble gases The Group 18 elements are called the noble gases. They are completely unreactive. They do not undergo any naturally occurring reactions. However, chemists have made artificial compounds that contain some of the noble gases.

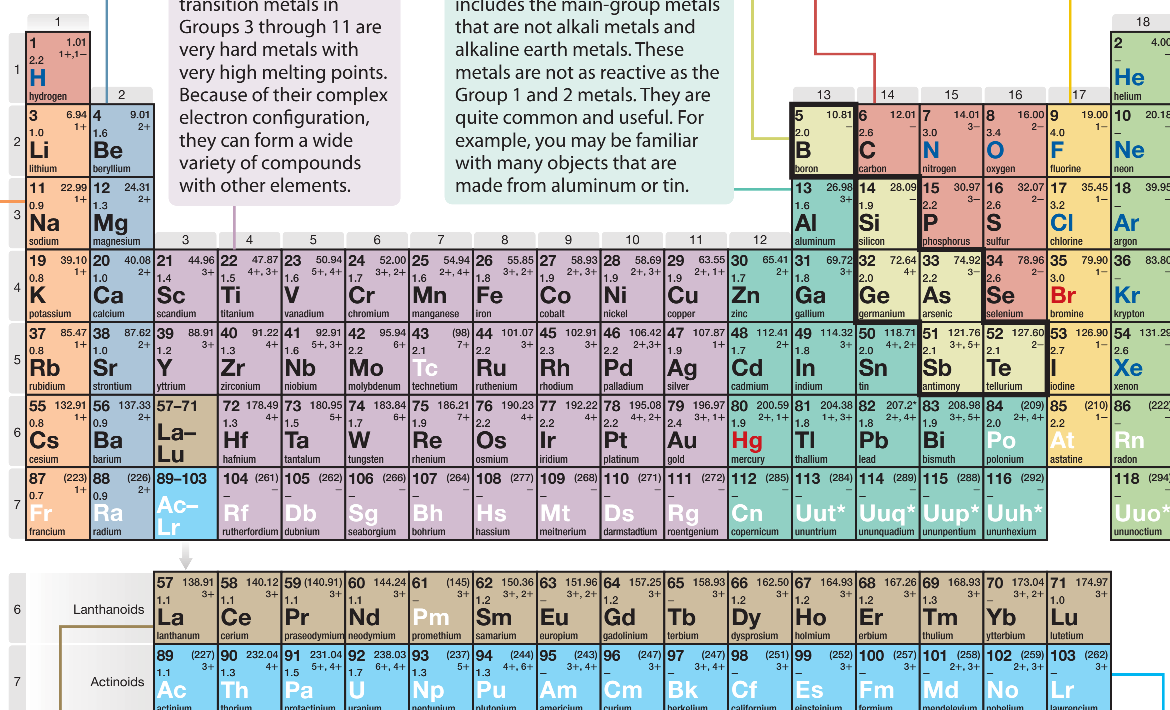
alkaline earth metals The elements in Group 2 are called the alkaline earth metals. They are reactive, but less so than the alkali metals.

metalloids Metalloids have properties that are between those of the metals and non-metals. Many are shiny solids but they are poor conductors of electric current and are brittle.

halogens The elements in Group 17 are called the halogens. They are reactive non-metals.

transition metals The transition metals in Groups 3 through 11 are very hard metals with very high melting points. Because of their complex electron configuration, they can form a wide variety of compounds with other elements.

other metals This category includes the main-group metals that are not alkali metals and alkaline earth metals. These metals are not as reactive as the Group 1 and 2 metals. They are quite common and useful. For example, you may be familiar with many objects that are made from aluminum or tin.



lanthanoids The inner transition elements in Period 6 are called the lanthanoids, because the first element is lanthanum. They are sometimes called the rare earth elements. For many years, chemists had difficulty separating them from one another. However, techniques were finally developed to purify them. Some rare earth elements are used in the advanced batteries that are being developed for hybrid cars.

actinoids The inner transition elements in Period 7 are called the actinoids, because the first element is actinium. These elements have no stable isotopes. As a consequence, they are all radioactive. In fact, all of the elements beyond uranium are not naturally occurring and can only be produced artificially.

Figure 1.13 Each colour in this periodic table represents a group of elements that have similar and unique properties.

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Categorizing Elements According to More General Properties

The colours in the periodic table in **Figure 1.14** show another way to categorize the elements. These categories are based on the general properties of the elements.

The elements shaded in blue are metals. Recall from previous science courses that all metals, except mercury, are solid at room temperature. (Mercury is a liquid.) Metals tend to be shiny, are good conductors of electric current, and are malleable and ductile.

The elements shaded in yellow are non-metals. Some non-metals are solid at room temperature, some are gases, and one (bromine) is a liquid. Non-metals are not shiny, do not conduct electric current, and are not malleable or ductile.

The elements shaded in green are metalloids. Their properties are between those of metals and non-metals. In their pure form, many metalloids look like metals, but they are brittle and often poor conductors of electric current. For example, silicon is shiny, but it is brittle and a poor conductor. It is an important semiconductor, used in transistors and integrated circuits in computer chips.

Categorizing According to Blocks of Elements in the Periodic Table

When you look at the periodic table in **Figure 1.12**, you can imagine cutting it into rectangles or blocks. These blocks are indicated by brackets across the top of the table and are based on the electron configurations of the elements.

Main-group Elements

Groups 1, 2, and 12 through 18 are the *main-group elements*. Varied in their chemical and physical properties, they are the most prevalent elements on Earth. The number of valence electrons, with the exception of the elements in Group 12, is completely predictable from the group number. The number of valence electrons increases from one to eight going from left to right (skipping Group 12) across the main-group elements. Although Group 12 does not fit into this pattern, it is often included with the main-group elements because its elements are chemically more similar to the main-group elements than to any other elements.

Transition Elements

The centre of the table contains the *transition elements*, sometimes called the transition metals. These elements make the periodic table 18 columns wide because atoms of some of the elements can have up to 18 electrons in their outer shell. Thus, their electron configurations are more complex than those of the main-group elements.

Inner Transition Elements

At the bottom of the table lie two rows called the *inner transition elements*. These elements fit between columns 3 and 4. Notice that, in **Figure 1.12**, the square in Group 3 of Period 6 reads "La–Lu," meaning that all of the elements from lanthanum through lutetium belong there. The square in Group 3 of Period 7 reads "Ac–Lr," indicating the location of the elements from actinium through lawrencium. Atoms of the inner transition elements can have as many as 32 electrons in some of their valence shells.

Learning Check

7. How did Mendeleev organize his periodic table?
8. State the periodic law and explain its meaning.
9. Compare and contrast groups and periods.
10. Explain why each period ends with a noble gas.
11. Describe the basis for the different categories of the elements in the periodic table.
12. Use a graphic organizer such as a main idea web to distinguish and describe key characteristics of the categories of elements in the periodic table.

Examples of Some Properties and Uses of Metals, Non-metals, and Metalloids

Silver

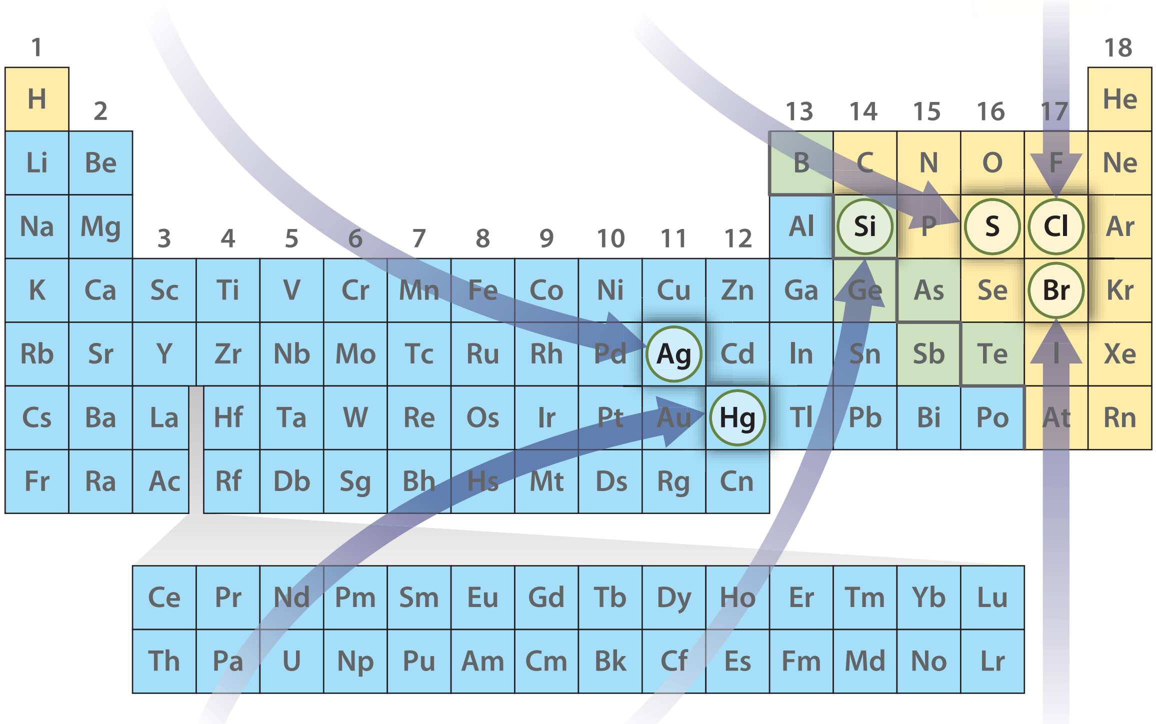
Silver, a metal, is ductile and can be drawn into a wire and shaped into coils.

Sulfur

Sulfur, a non-metal, is a yellow solid at room temperature. It is used in the processing of rubber and it is an ingredient in gunpowder.

Chlorine

Chlorine, a non-metal, is a greenish-yellow gas. It is very toxic and can damage the respiratory tract.



Mercury

Mercury is the only metal that is liquid at room temperature. But, like the other metals, it is shiny and can conduct electric current.

Silicon

Silicon, a metalloid, is purified and shaped into ingots, which are sliced into wafers that are less than a millimetre thick. These wafers are used for making solar cells and computer chips.

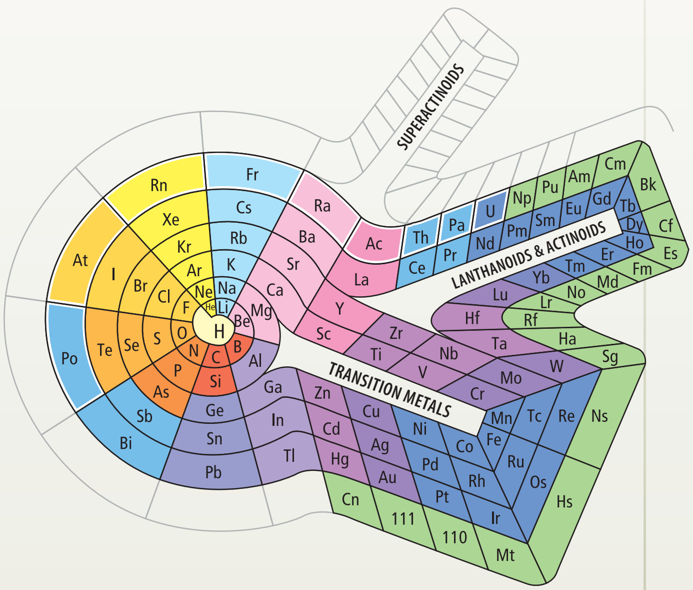
Bromine

Bromine, a non-metal, is a volatile, reddish-brown liquid at room temperature. It is used in water purification and in pesticides.

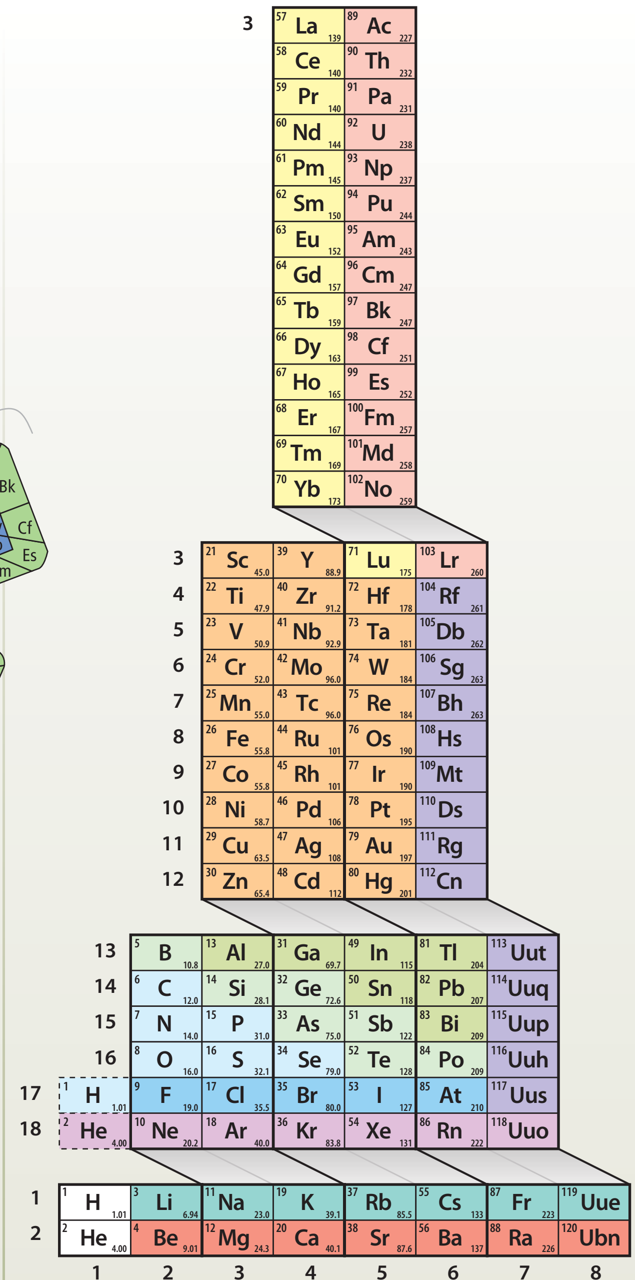
Figure 1.14 Some properties and uses of metals, metalloids, and non-metals are summarized here.

Alternative Forms of the Periodic Table

The commonly used periodic table, as shown in **Figure 1.12**, is convenient for many purposes. However, it is only one of several possible designs. Some chemists have proposed the designs in **Figure 1.15** for a table of the elements to highlight certain properties of the elements.



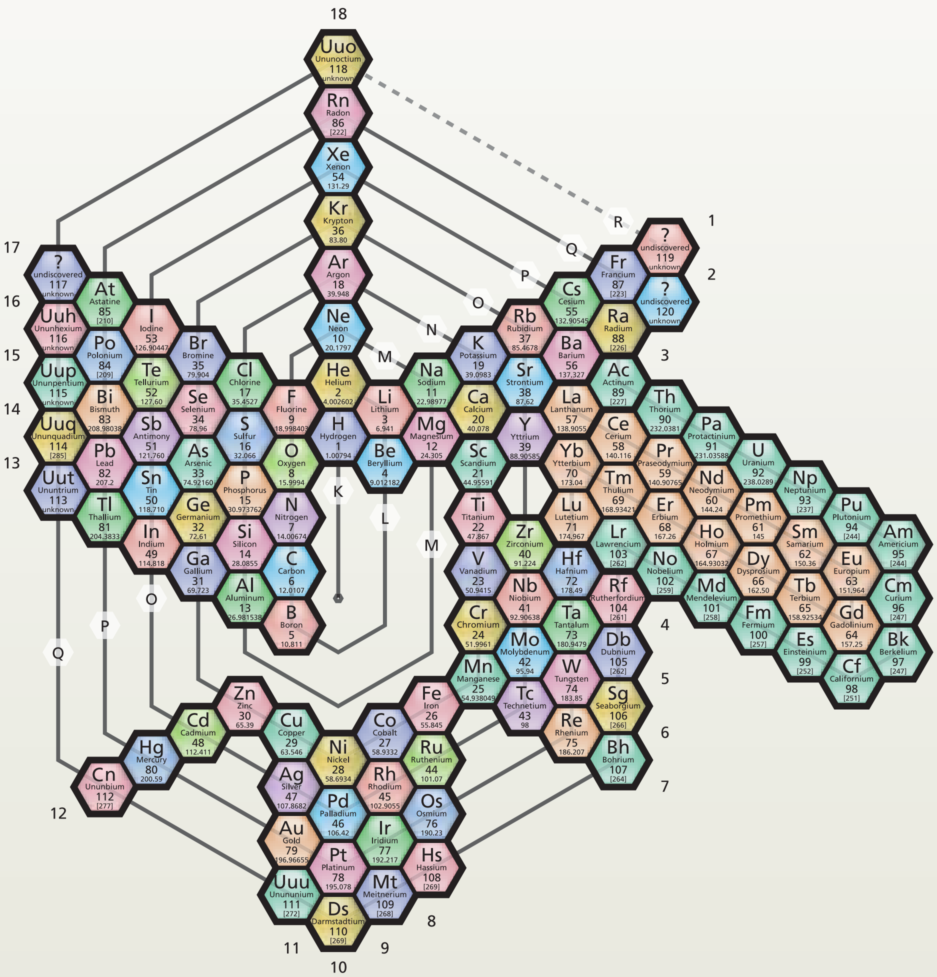
In this circular table, hydrogen is at the centre, and each circumference contains one period. Each group is in the shape of a piece of pie. The transition elements form an arm extending out from the circle. The inner transition elements form another arm extending out from the transition elements. This design emphasizes that the increase in atomic number is continuous. The circle highlights the repeating nature of the properties of the elements.



This pyramidal periodic table is separated into four blocks, based on the electron configurations of the elements. You will learn more about electron configurations if you take more advanced chemistry courses. Notice, however, that the inner transition elements form the top of the pyramid, with the transition elements just below them. The base of the pyramid consists of the main-group elements. Each group forms a horizontal row.

Figure 1.15 These are just a few of the alternative periodic tables that some chemists have suggested.

This student has constructed a unique—and edible—version of the periodic table.



In this "periodic spiral," hydrogen is in the centre. As you go around the spiral clockwise, the atomic number increases. The main-group elements, the alkali and alkaline earth metals, the inner transition metals, and the transition metals all form separate clusters. The noble gases form a line by themselves. Zinc, cadmium, and mercury are also in a line by themselves because they have some characteristics of main-group elements and some characteristics of transition metals. This periodic spiral comes with interactive software that contains a wealth of information about the elements.

***Identify** the alkali metals, alkaline earth metals, halogens, noble gases, actinoids, and lanthanoids in this periodic table.*

Section 1.2 REVIEW

Section Summary

- Mendeleev developed the periodic table by first listing the elements in order of increasing atomic mass. Then, when the chemical properties of an element resembled those of a previous element in the list, he put this element alongside the previous element. With a little adjusting, Mendeleev developed a table of elements with increasing mass in the columns and similar properties in the rows.
- Elements are categorized as main-group, transition, and inner transition elements, based on their electron configurations.
- Elements are categorized as metals, metalloids, and non-metals, based on their chemical properties.
- Several groups of elements are given specific names due to their uniquely similar properties. Group 1 elements are called the alkali metals, Group 2 elements are called the alkaline earth metals, Group 17 elements are called the halogens, and Group 18 elements are called the noble gases.
- Many alternative forms of the periodic table have been developed to highlight specific properties of the elements.

Review Questions

1. K/U When Mendeleev was working on his periodic table, he listed the elements according to their mass. He discovered that he had to reverse the order of a few of the elements to make them fit the pattern of chemical properties. Why were these elements out of order?
2. K/U Explain why some elements were missing in Mendeleev's periodic table.
3. K/U What characteristic is the same for all the main-group elements in a given period? What characteristic is the same for all the main-group elements in a group?
4. T/I Sodium metal is usually stored in oil. Find sodium in the periodic table. Based on its position in the periodic table, why do you think that sodium must be stored in oil?
5. A The platter shown here is made from copper. Why could silicon not be used to make objects such as this?

6. K/U Name two characteristics that distinguish main-group elements from transition or inner transition elements.
7. K/U Which category—metals, metalloids, or non-metals—includes elements that are gases at room temperature?
8. T/I List the following elements in order, from best to worst conductor of electric current: silicon, copper, iodine.
9. T/I If the inner transition elements were inserted into the periodic table between Groups 3 and 4 in Periods 6 and 7, how many columns wide would the table be? Explain your answer.
10. K/U Name three different categories into which the Group 17 elements could be classified.
11. K/U Why are the lanthanoids sometimes called rare earth elements?
12. A Strontium is sometimes called a "bone seeker" because, when ingested, it is deposited in bones and remains there for long periods of time. Find strontium in the periodic table. Offer a possible explanation for why strontium is called a "bone seeker."
13. T/I Examine each of the following pairs of elements. State which element is the most reactive, and explain how you made your choice.
    a. Na or Mg **b.** Br or Kr **c.** H or He
14. K/U The photograph below shows what happened when a sample of a pure element was dropped in water. Name two elements that could have caused this reaction.

15. A Living tissues are made up of just a few elements. In what category are most of these elements found?
16. C Create a chart that summarizes the different types of periodic tables presented in this chapter and include the benefits of each model.