3.2: The Periodic Law and the Periodic Table

Prior to the 1700s, the number of known elements was relatively small, consisting mostly of the metals used for coinage, jewelry, and weapons. From the early 1700s to the mid-1800s, however, chemists discovered over 50 new elements. The first attempt to organize these elements according to similarities in their properties was made by the German chemist Johann Döbereiner (1780–1849), who grouped elements into *triads*: A triad consisted of three elements with similar properties. For example, Döbereiner formed a triad out of barium, calcium, and strontium, three fairly reactive metals. About 50 years later, English chemist John Newlands (1837–1898) organized elements into *octaves*, in analogy to musical notes. When arranged this way, the properties of every eighth element were similar, much as every eighth note in the musical scale is similar. Newlands endured some ridicule for drawing an analogy between chemistry and music, including the derisive comments of one colleague who asked Newlands if he had ever tried ordering the elements according to the first letters of their names.

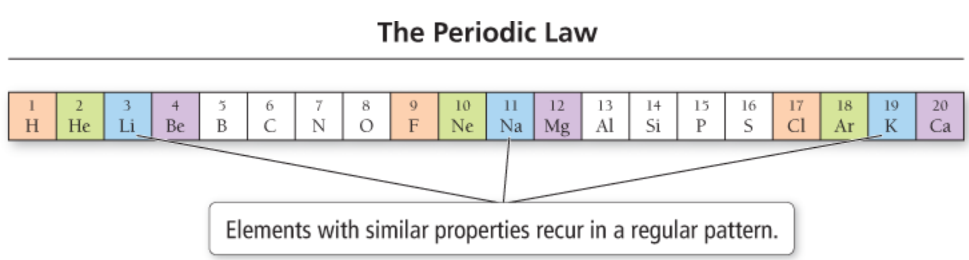
Dmitri Mendeleev, a Russian chemistry professor who proposed the periodic law and arranged early versions of the periodic table, was honored on a Soviet postage stamp.

The modern periodic table is credited primarily to the Russian chemist Dmitri Mendeleev (1834–1907), even though a similar organization had been suggested by the German chemist Julius Lothar Meyer (1830–1895). In 1869, Mendeleev noticed that certain groups of elements had similar properties. He also found that when he listed elements in order of increasing mass, these similar properties recurred in a periodic pattern (Figure 3.1). Mendeleev summarized these observations in the **periodic law**:

> **When the elements are arranged in order of increasing mass, certain sets of properties recur periodically.**

Figure 3.1 Recurring Properties

These elements are listed in order of increasing atomic number. Elements with similar properties are represented with the same color. Notice that the colors form a repeating pattern, much like musical notes form a repeating pattern on a piano keyboard.



Mendeleev organized the known elements in a table consisting of a series of rows in which mass increases from left to right. He arranged the rows so that elements with similar properties fall in the same vertical columns (Figure 3.2).

Figure 3.2 Making a Periodic Table

We can arrange the elements from Figure 3.1 in a table where atomic number increases from left to right and elements with similar properties (as represented by the different colors) are aligned in columns.

A Simple Periodic Table

1 H							2 He
3 Li	4 Be	5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca						

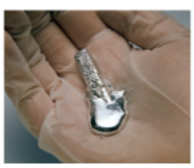
Elements with similar properties fall into columns.

Mendeleev's arrangement was a huge success, allowing him to predict the existence and properties of yet undiscovered elements such as eka-aluminum, later discovered and named gallium and eka-silicon, later discovered and named germanium. (*Eka* means the one beyond or the next one in a family of elements. So, eka-silicon means the element beyond silicon in the same family as silicon.) The properties of these two elements are summarized in Figure 3.3.

Figure 3.3 Eka-aluminum and Eka-silicon

Mendeleev's arrangement of elements in the periodic table allowed him to predict the existence of these elements, now known as gallium and germanium, and to anticipate their properties.

Gallium (eka-aluminum)



	Mendeleev's predicted properties	Actual properties
Atomic mass	About 68 amu	69.72 amu
Melting point	Low	29.8 °C
Density	5.9 g/cm^3	5.90 g/cm^3
Formula of oxide	X_2O_3	Ga_2O_3
Formula of chloride	XCl_3	$GaCl_3$

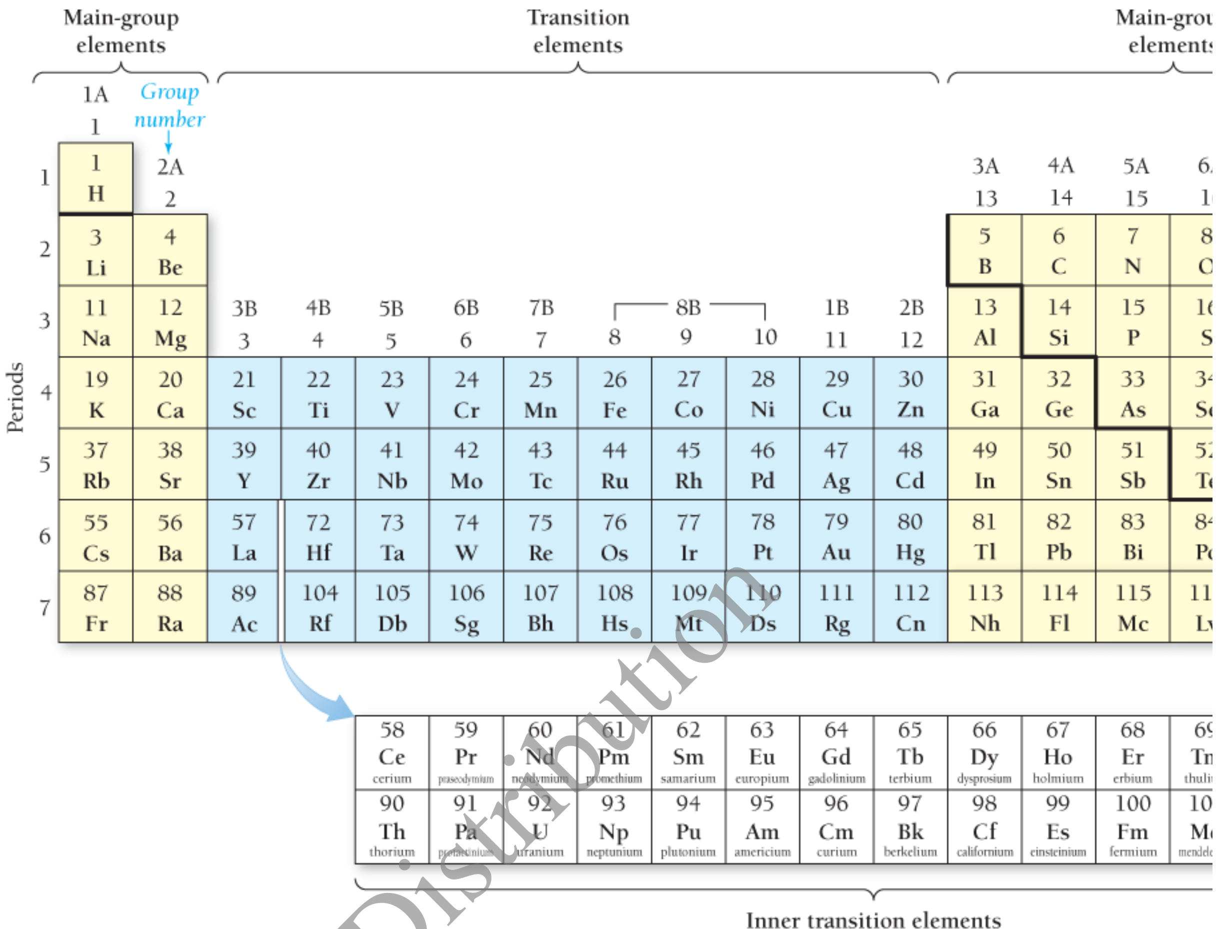
Germanium (eka-silicon)

	Mendeleev's predicted properties
Atomic mass	About 72 amu
Density	5.5 g/cm^3
Formula of oxide	XO_2
Formula of chloride	XCl_4

However, Mendeleev did encounter some difficulties. For example, according to accepted values of atomic masses, tellurium (with higher mass) should come *after* iodine. But, based on their properties, Mendeleev placed tellurium *before* iodine and suggested that the mass of tellurium was erroneous. The mass was correct; later work by the English physicist Henry Moseley (1887–1915) showed that listing elements according to *atomic number*, rather than atomic mass, resolved this problem and resulted in even better correlation with elemental properties. Mendeleev's original listing evolved into the modern periodic table shown in Figure 3.4. In the modern table, elements are listed in order of increasing atomic number rather than increasing relative mass. The modern periodic table also contains more elements than Mendeleev's original table because more have been discovered since then. The discovery of new elements continues to this day. In 2015, four new elements—113, 115, 117, and 118—were discovered and added to the periodic table. One of those elements (element 113) was the first to be attributed to researchers in Asia.

Figure 3.4 The Modern Periodic Table

The elements in the periodic table fall into columns. The two columns at the left and the six columns at the right constitute the main-group elements. The elements that constitute any one column are a *group* or *family*. The properties of main-group elements can generally be predicted from their position in the periodic table. The properties of the elements in the middle of the table, known as transition elements, and those at the bottom of the table, known as the inner transition elements, are less predictable based on their position within the table.



We divide the periodic table, as shown in Figure 3.4, into **main-group elements**, whose properties tend to be largely predictable based on their position in the periodic table, and **transition elements** (or **transition metals**) and inner transition elements, whose properties tend to be less predictable based simply on their position in the periodic table. Main-group elements are in columns labeled with a number and the letter A. Transition elements are in columns labeled with a number and the letter B. An alternative numbering system does not use letters, but only the numbers 1–18. Both numbering systems are shown in most of the periodic tables in this book. Each column within the main-group regions of the periodic table is a **family** or **group** of elements. A family of elements has similar properties as observed by Mendeleev.

Notice the scientific approach in practice in the history of the periodic table. A number of related observations led to a scientific law—the periodic law. Mendeleev's table, an expression of the periodic law, has predictive power, as laws usually do. However, it does not explain *why* the properties of elements recur or *why* certain elements have similar properties. Quantum-mechanical theory explains the electronic structure of atoms, which in turn determines their properties. Since a family of elements has similar properties, we expect the electronic structure of their atoms to have similarities as well. We now turn to examining those similarities.

Conceptual Connection 3.1 The Periodic Table

Interactive