6.3 Putting the Elements in Order

By 1864, chemists had identified 63 unique elements. To identify these elements, chemists described many of their chemical and physical properties. They grouped the elements according to these properties, just as you grouped some elements in the previous section. Antoine Lavoisier, a French scientist in the late 1700s, classified the known elements into four groups: metals, gases, non-metals, and "earths." This classification was based on physical properties, such as electrical conductivity, lustre, and ductility. Other scientists had classified the elements by how they reacted with other elements. Neither classification, however, included all the elements.

Ordering by Properties

Working in the mid-1800s, a Russian scientist named Dmitri Mendeleev (Figure 1) tried to find a way of organizing all the elements to do more than just provide a listing of the known elements and their properties. At that time, it was known that each element had a specific and unique mass. Scientists such as John Dalton had discovered that the masses of the elements involved in chemical reactions are always in certain proportions. For example, two parts hydrogen and one part oxygen always combine to form water (H_2O). When the reaction is complete with no hydrogen or oxygen left over, the mass of oxygen used is eight times the mass of hydrogen. This means that the mass of oxygen is 16 times the mass of hydrogen because there is one part oxygen to two parts hydrogen. By studying reactions, scientists could tell how heavy one element was in relation to another. When the elements were listed in order of increasing mass (from lightest to heaviest), Mendeleev noted that certain other properties seemed to repeat with a regular pattern, as shown in Figure 2.

H	Li	Be	B	C	N	O	F	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr

Figure 2 Mendeleev noted that elements with common properties appear at regular intervals when ordered by mass, like the low-density reactive metals highlighted (in red) above.

To order the elements, Mendeleev wrote the known elements on cards, and listed their properties. He laid out the cards like a game of solitaire, moving and grouping them in different ways. Eventually, he sorted out the cards in order of increasing mass, from left to right. When the properties of elements periodically repeated, he began a new row each time to create a Periodic Table of the Elements. This periodic table listed the elements in horizontal rows (periods), with masses increasing from left to right. It also formed vertical columns (groups) of elements with common properties.

6A *Investigation*

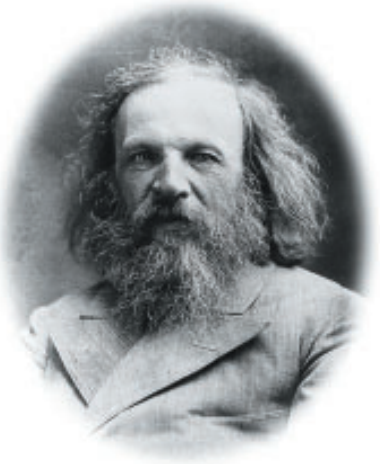


Figure 1 Dmitri Mendeleev observed patterns which allowed him to organize the elements into groups.

LEARNING TIP

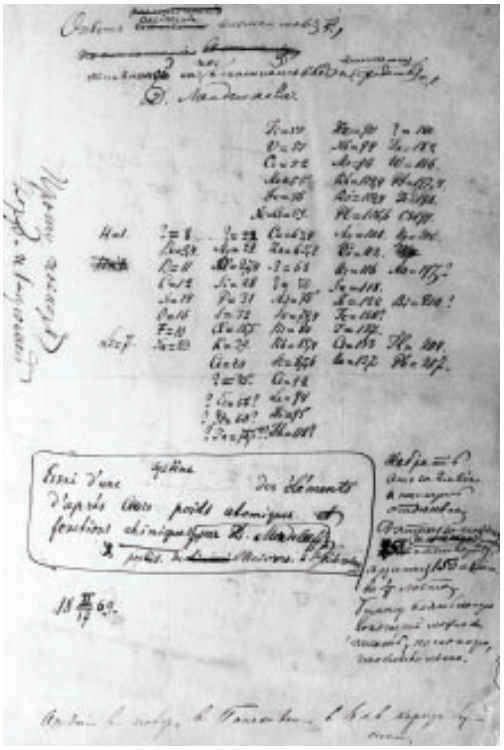
As you study Figure 2, explain to a partner how Mendeleev's Periodic Table of Elements simplified the complex world of chemical reactions.

6A *Investigation*

Creating a Periodic Table

To perform this investigation, turn to page 197.

In this investigation, you will create a periodic table using properties of hypothetical elements.



(a)

Groups		I	II	III	IV	V	VI	VII	VIII
Formulas of Compound		R_2O ——	RO ——	R_2O_3 ——	RO_2 H_4R	R_2O_5 H_3R	RO_3 H_2R	R_2O_7 HR	RO_4 ——
Periods	1	H(1)							
	2	Li(7)	Be(9.4)	B(11)	C(12)	N(14)	O(16)	F(19)	
	3	Na(23)	Mg(24)	Al(27.3)	Si(28)	P(31)	S(32)	Cl(35.5)	
	4	K(39)	Ca(40)	–(44)	Ti(48)	V(51)	Cr(52)	Mn(55)	Fe(56) Co(59) Ni(59) Cu(63)
	5	[Cu(63)]	Zn(65)	–(68)	–(72)	As(75)	Se(78)	Br(80)	
	6	Rb(85)	Sr(87)	?Yt(88)	Zr(90)	Nb(94)	Mo(96)	–(100)	Ru(104) Rh(104) Pd(105) Ag(108)
	7	[Ag(108)]	Cd(112)	In(113)	Sn(118)	Sb(122)	Te(125)	I(127)	

(b)

Figure 3 (a) This is a page from Mendeleev's original notes, showing the Periodic Table as a work in progress. (b) The version of the Periodic Table that was published in 1872.

Figure 4 Sodium metal, like all the elements in the Group I column, reacts with water to produce hydrogen gas. The heat that is released in this reaction can ignite the hydrogen.

Other scientists had proposed something similar to Mendeleev's table, but Mendeleev used a breakthrough approach: he left gaps when the properties of the next-heaviest element did not match the properties above it in the column (Figure 3).

Events that occur over and over, in a regular pattern, are called "periodic" events. The observation that patterns of properties would repeat was stated as the following: when elements are arranged in order of increasing mass, chemical and physical properties form patterns that repeat at regular intervals. Mendeleev's Periodic Table is based on this.

Predicting with Properties

The vertical groups of elements in Mendeleev's table share properties. Look at the Periodic Table in Figure 3. In the Group I column are lithium, sodium, potassium, and rubidium. These low-density metals all react violently with water (Figure 4).

Based on the properties of the elements in these groups, Mendeleev predicted some of the properties, (such as density and melting point) of elements that would fill the gaps in his table. He predicted that elements would eventually be isolated or discovered to fill his table. Soon, scandium (1879), germanium (1886), and gallium (1895), were discovered, and they displayed properties in accordance with Mendeleev's predictions.

Sometimes, elements did not fit into the right groups if Mendeleev kept them in order of increasing mass. In these situations, he always moved the elements into the vertical groups based on their physical and chemical properties. In later years, other scientists re-measured most of these "out of order" elements, and found that the new, more accurate measurements agreed with most of the chemical groupings. They found only two pairs that remained out of sequence. Argon and potassium are one of these pairs.

The predictive power of the Periodic Table made it extremely useful to chemists, and it was continually modified and updated as new elements were discovered and fit into the puzzle. In 1892, Sir Walter Raleigh and William Ramsay discovered the atmospheric gas argon, which was important for its non-reactive nature. Noting that argon needed a new column (Group 0) in the Periodic Table, Ramsay searched for more non-reactive gases and soon isolated neon, krypton, and xenon from Earth's atmosphere. These elements form a group that we now call the noble gases (Figure 5).

Figure 5 Mendeleev's updated Periodic Table of the Elements, which includes the newly-discovered noble gases in Group 0.

Pointing the Way to the Future

Mendeleev's table was not perfect. It contained some errors and inconsistencies due to incomplete or incorrect data. Manganese, for example, was included with the chemical grouping of chlorine, bromine, iodine, and fluorine. Like most scientific ideas, however, the Periodic Table is a model that has evolved through the work of others, adapting to new information. The table most often used (and reproduced at the back of this book) achieved its general form in 1940. This table also identifies elements that are metals, non-metals, and metalloids. GO

Mendeleev, by using the collective observations and analysis of the chemistry community, created a model that not only explained how the elements are grouped, but also pointed the way to understanding the nature of matter itself.

Did You KNOW?

Other Periodic Tables

Julius Meyer studied under the same university professor as Mendeleev, and also noted the periodic appearance of properties. Meyer produced his own periodic table, but Mendeleev published one year earlier, and so is given credit for the invention of the Periodic Table. But neither scientist was the first to note that properties appeared in a regular pattern.

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To learn more about different versions of the Periodic Table, visit www.science.nelson.com GO

6.3 CHECK YOUR Understanding

1. (a) Explain the process of classification.
   (b) Give an example from your everyday life of how things are classified.
   (c) Describe the advantages of classifying a collection of objects or materials.
2. State the periodic law in your own words.
3. Explain why the word "periodic" is used in the name of the table of the elements.
4. Which property did Mendeleev primarily use to classify the elements?
5. (a) Why did Mendeleev leave gaps in his Periodic Table?
   (b) What did Mendeleev predict about the "undiscovered" elements in the gaps?
6. Which elements, discovered in the late 1800s, matched closely with Mendeleev's predictions?
7. (a) Which was the first noble gas discovered on Earth?
   (b) Where is this gas found?
   (c) Why did Ramsay search for more noble gases?
   (d) Why did the elements argon, neon, krypton, xenon, and helium need their own, new group in the Periodic Table?
8. What feature(s) of Mendeleev's table made it so useful and accepted by chemists?
9. Name two undiscovered elements that Mendeleev predicted. Did the eventual discovery of these elements provide evidence for the concept of the Periodic Table? Explain your thinking.
10. Refer to Mendeleev's Periodic Table on the right and compare it with the modern Periodic Table at the back of this book.
    (a) Which elements are no longer included in Group I?
    (b) Which element from Mendeleev's seventh column is now considered out of place?
11. When Mendeleev had to make a choice between grouping based on mass or grouping by similar properties, which did he choose? Why do you think he made this choice?
12. The quality of any model is how well it explains what happens in the world. How well did Mendeleev's table explain the chemistry of his time? Does it still have the power to explain? Why or why not?
13. Was the Periodic Table invented by Mendeleev or discovered by him? Explain your thinking.
14. The Periodic Table was welcomed by chemists because it organized and included all the known elements. Did the table explain why or how this organization occurred? Explain your thinking.
15. Suggest three possible questions that Mendeleev may have asked when he was attempting to organize the elements.

Groups		I	II	III	IV	V	VI	VII	VIII
Formulas of Compound		R_2O ——	RO ——	R_2O_3 ——	RO_2 H_4R	R_2O_5 H_3R	RO_3 H_2R	R_2O_7 HR	RO_4 ——
Periods	1	H(1)							
	2	Li(7)	Be(9.4)	B(11)	C(12)	N(14)	O(16)	F(19)	
	3	Na(23)	Mg(24)	Al(27.3)	Si(28)	P(31)	S(32)	Cl(35.5)	
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	7	[Ag(108)]	Cd(112)	In(113)	Sn(118)	Sb(122)	Te(125)	I(127)	

Figure 6