2.2 The Periodic Table and Chemical Properties

The periodic table organizes the elements according to their properties. Elements are listed in rows by increasing order of atomic number. Rows are arranged in such a way that elements with similar properties line up in vertical columns. Rows are called periods, and columns are called families or groups. Each element in the table is recorded using its name, symbol, atomic number, atomic mass, and common ion charge(s). Two families of metals are the alkali metals and the alkaline earth metals. Two families of non-metals are the halogens and the noble gases.

Words to Know

alkali metals
alkaline earth metals
atomic mass
atomic number
halogens
metalloid
multiple ion charge
noble gases

In the 19th century, chemists began looking for a way to organize their observations of the elements. Could elements having similar properties be grouped together? What sort of properties could be used? In 1867, a Russian chemist and teacher, Dmitri Mendeleev (Figure 2.10), wrote down the name of every known element on a separate card, like the one shown in Figure 2.11. He also wrote down properties he thought were important, such as density, colour, melting point, and boiling point. Then he sorted and re-sorted the cards into rows and columns until he found a pattern.

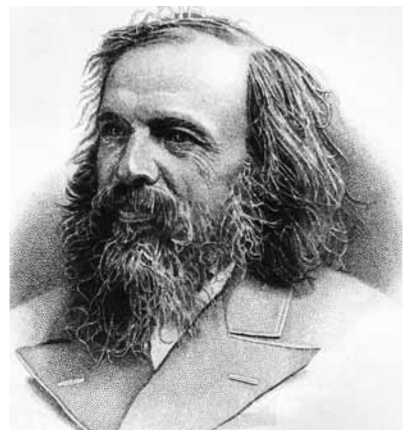


Figure 2.10 Dmitri Mendeleev was a teacher and chemist born in Russia.

Many scientists were trying to organize the elements into a table, but Mendeleev's special insight was that there needed to be holes in the table—places left for elements that had yet to be discovered. From the placement of the holes and the properties of the surrounding elements, Mendeleev was able to predict the properties of elements that were later discovered.

Did You Know?

Harriet Brooks (1876–1933) was a Canadian researcher who worked with Ernest Rutherford. She was one of the early scientists who found that a gas being released from the element radium was in fact a new element: radon.

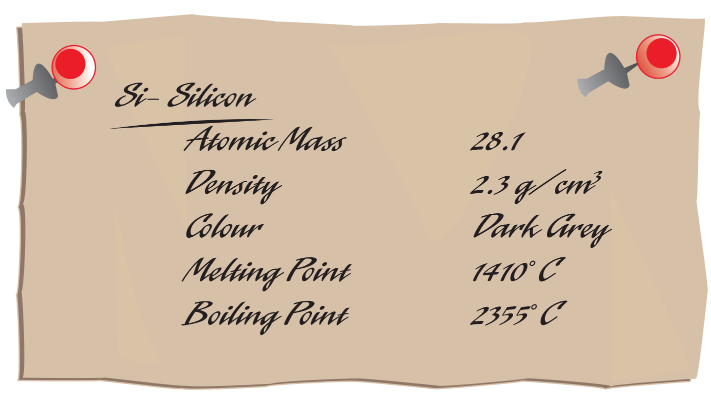


Figure 2.11 Mendeleev wrote down the known properties of each element on a card like this.

2-2A Periodic Puzzle

Think About It

Mendeleev sorted his cards until a pattern emerged. In this activity, you will arrange element cards in groups according to their atomic mass and other properties.

Materials

- element cards provided by your teacher
- scissors

What to Do

1. Use the scissors to cut apart the element cards. Line up the cards in order of increasing mass.
2. Examine the cards to find properties that are similar enough to justify placing certain elements above or below each other in a chemical family.
3. When you are satisfied with your arrangement, explain to a partner how you made your choices.
4. Make any improvements to your classification that you can think of.
5. As a large group, the class must come to a decision as to which classification is the best.

The Periodic Table

We still use Mendeleev's table today, but we call it the periodic table. The **periodic table** is a chart that organizes the elements according to their physical and chemical properties. The periodic table gives each element's name, symbol, atomic number, atomic mass, and ion change(s) (Figure 2.12).

- The **atomic number** is the number of protons in the nucleus of each atom of an element. It is always a whole number.

  Pattern: Atomic numbers increase one by one through the periodic table. Notice how they start with number 1 at the top left and increase in a regular way down the table (Figure 2.13 on the next page).

- **Atomic mass** is the mass of an average atom of an element. It is always written as a decimal number and is measured in the **atomic mass unit** (amu).

  Pattern: Atomic mass tends to increase along with atomic number. There are some exceptions, such as between cobalt and nickel.

- The **ion charge** is an electric charge that forms on an atom when it gains or loses electrons. Any electrically charged atom is called an **ion**. An atom that has gained electrons is a negative ion because the extra electrons make it negative. An atom that has lost electrons is a positive ion because the loss of electrons removes negative charge. Some elements have a **multiple ion charge**. These elements can form ions in more than one way.

  Pattern: Elements on the left side of the table generally form positive ions. Elements on the right side, except for the last column, generally form negative ions. Elements that are in the same column often form ions with the same charge as other elements in that column.

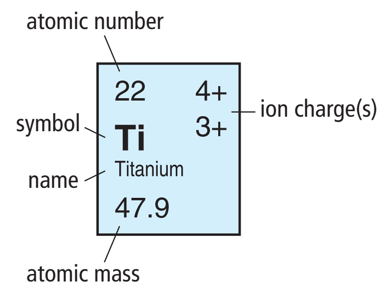


Figure 2.12 Each element has its own box in the periodic table.

Suggested Activity

Think About It 2-2B on page 58

Periodic Table of the Elements

metal | metalloid | non-metal

Atomic Number → 22; Symbol → Ti; Name → Titanium; Atomic Mass → 47.9; Ion charge(s) → 4+ 3+

O natural | Db synthetic

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.0 +																	2 He Helium 4.0 0
2	3 Li Lithium 6.9 +	4 Be Beryllium 9.0 2+											5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0 3–	8 O Oxygen 16.0 2–	9 F Fluorine 19.0 –	10 Ne Neon 20.2 0
3	11 Na Sodium 23.0 +	12 Mg Magnesium 24.3 2+											13 Al Aluminum 27.0 3+	14 Si Silicon 28.1	15 P Phosphorus 31.0 3–	16 S Sulphur 32.1 2–	17 Cl Chlorine 35.5 –	18 Ar Argon 39.9 0
4	19 K Potassium 39.1 +	20 Ca Calcium 40.1 2+	21 Sc Scandium 45.0 3+	22 Ti Titanium 47.9 4+ 3+	23 V Vanadium 50.9 5+ 4+	24 Cr Chromium 52.0 3+ 2+	25 Mn Manganese 54.9 2+ 3+ 4+	26 Fe Iron 55.8 3+ 2+	27 Co Cobalt 58.9 2+ 3+	28 Ni Nickel 58.7 2+ 3+	29 Cu Copper 63.5 2+ 1+	30 Zn Zinc 65.4 2+	31 Ga Gallium 69.7 3+	32 Ge Germanium 72.6 4+	33 As Arsenic 74.9 3–	34 Se Selenium 79.0 2–	35 Br Bromine 79.9 –	36 Kr Krypton 83.8 0
5	37 Rb Rubidium 85.5 +	38 Sr Strontium 87.6 2+	39 Y Yttrium 88.9 3+	40 Zr Zirconium 91.2 4+	41 Nb Niobium 92.9 3+ 5+	42 Mo Molybdenum 95.9 2+ 3+	43 Tc Technetium (98) 7+	44 Ru Ruthenium 101.1 3+ 4+	45 Rh Rhodium 102.9 3+ 4+	46 Pd Palladium 106.4 2+ 4+	47 Ag Silver 107.9 1+	48 Cd Cadmium 112.4 2+	49 In Indium 114.8 3+	50 Sn Tin 118.7 4+ 2+	51 Sb Antimony 121.8 3+ 5+	52 Te Tellurium 127.6 2–	53 I Iodine 126.9 –	54 Xe Xenon 131.3 0
6	55 Cs Cesium 132.9 +	56 Ba Barium 137.3 2+	57 La Lanthanum 138.9 3+	72 Hf Hafnium 178.5 4+	73 Ta Tantalum 180.9 5+	74 W Tungsten 183.8 6+	75 Re Rhenium 186.2 4+ 7+	76 Os Osmium 190.2 3+ 4+	77 Ir Iridium 192.2 3+ 4+	78 Pt Platinum 195.1 4+ 2+	79 Au Gold 197.0 3+ 1+	80 Hg Mercury 200.6 2+ 1+	81 Tl Thallium 204.4 1+ 3+	82 Pb Lead 207.2 2+ 4+	83 Bi Bismuth 209.0 3+ 5+	84 Po Polonium (209) 2+ 4+	85 At Astatine (210) –	86 Rn Radon (222) 0
7	87 Fr Francium (223) +	88 Ra Radium (226) 2+	89 Ac Actinium (227) 3+	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)	112 Uub* Ununbium (285)	113 Uut* Ununtrium (284)	114 Uuq* Ununquadium (289)	115 Uup* Ununpentium (288)	116 Uuh* Ununhexium (292)		

* Temporary names

58 Ce Cerium 140.1 3+ 4+	59 Pr Praseodymium 140.9 3+ 4+	60 Nd Neodymium 144.2 3+	61 Pm Promethium (145) 3+	62 Sm Samarium 150.4 3+ 4+	63 Eu Europium 152.0 3+ 2+	64 Gd Gadolinium 157.3 3+	65 Tb Terbium 158.9 3+ 4+	66 Dy Dysprosium 162.5 3+	67 Ho Holmium 164.9 3+	68 Er Erbium 167.3 3+	69 Tm Thulium 168.9 3+ 2+	70 Yb Ytterbium 173.0 3+ 2+	71 Lu Lutetium 175.0 3+
90 Th Thorium 232.0 4+	91 Pa Protactinium 231.0 5+ 4+	92 U Uranium 238.0 6+ 4+ 5+	93 Np Neptunium (237) 5+ 3+ 4+ 6+	94 Pu Plutonium (244) 4+ 6+ 3+ 5+	95 Am Americium (243) 3+ 4+ 5+ 6+	96 Cm Curium (247) 3+	97 Bk Berkelium (247) 3+ 4+	98 Cf Californium (251) 3+	99 Es Einsteinium (252) 3+	100 Fm Fermium (257) 3+	101 Md Mendelevium (258) 2+ 3+	102 No Nobelium (259) 2+ 3+	103 Lr Lawrencium (262) 3+

Based on mass of C-12 at 12.00.

Any value in parentheses is the mass of the most stable or best known isotope for elements that do not occur naturally.

Figure 2.13 The periodic table of the elements

Metals, Non-metals, and Metalloids

Mendeleev arranged the elements according to their properties, which created some interesting patterns. For example, the elements form three groups: metals, non-metals, and metalloids. Notice in Table 2.2 below that **metalloids** are elements that share some properties with metals and some properties with non-metals.

Table 2.2 Properties of Metals, Non-metals, and Metalloids

	State at Room Temperature	Appearance	Conductivity	Malleability and Ductility
Metals	• solid except for mercury (a liquid)	• shiny lustre	• good conductors of heat and electricity	• malleable • ductile
Non-metals	• some gases • some solids • only bromine is a liquid	• not very shiny	• poor conductors of heat and electricity	• brittle • not ductile
Metalloids	• solids	• can be shiny or dull	• may conduct electricity • poor conductors of heat	• brittle • not ductile

A shortened form of the periodic table is shown in Figure 2.14 below that includes the metals, non-metals, and metalloids.

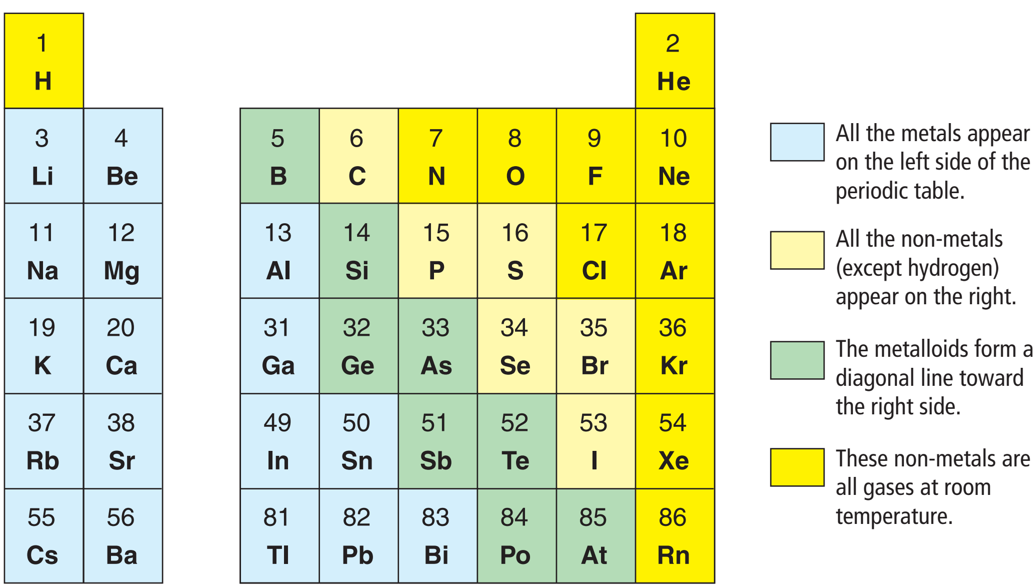


Figure 2.14 The metals, non-metals, and metalloids as they appear in the periodic table

Figure 2.16 Alkali metals are soft and highly reactive.

Periods and Families

Each horizontal row in the periodic table is called a **period**. The periods are numbered from one to seven. For example, hydrogen and helium are in the first period. Lithium is the first of eight elements in the second period.

Chemical families or groups are arranged in vertical columns in the periodic table. Elements in the same **chemical family** have similar physical and chemical properties. The families are in numbered columns 1 to 18 of the table. Four well-known groups are the alkali metals, the alkaline earth metals, the halogens, and the noble gases (Figure 2.15).

Alkali metals (Group 1 excluding hydrogen)
Li, Na, K, Rb, Cs, Fr

All the **alkali metals** are highly reactive (Figure 2.16), and reactivity increases as you go down the group. Alkali metals react with both oxygen and water. They have low melting points, all of which are below 200°C. The alkali metals are soft and can be cut with a knife. Cesium is softer and more reactive than lithium.

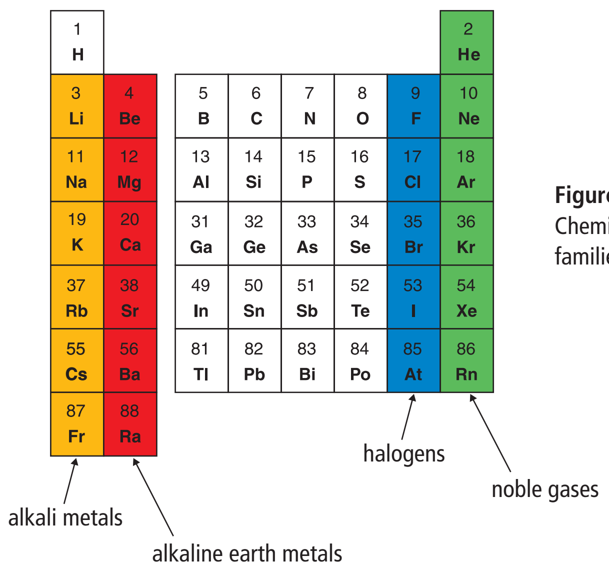


Figure 2.15 Chemical families

Figure 2.17 Calcium (A) and magnesium (B) are alkaline earth metals.

Alkaline earth metals (Group 2)
Be, Mg, Ca, Sr, Ba, Ra

Alkaline earth metals (Figure 2.17) are less reactive than the alkali metals but will burn in air if heated. They produce bright flames and are used in fireworks. For example, the classic red colour of fireworks is caused by strontium. Alkaline earth metals will also react with water but not as vigorously as alkali metals do. Calcium reacts more quickly than magnesium.

Halogens (Group 17)
F, Cl, Br, I, At

The **halogens** are non-metals and are highly reactive (Figure 2.18). Only fluorine and chlorine are gases at room temperature. Bromine is a liquid and iodine is a solid. Fluorine is the most reactive, and iodine is the least. Astatine is incredibly rare. No one has ever collected enough to determine its physical properties.

Figure 2.18 All the halogens are coloured and highly reactive.

Noble gases (Group 18)
He, Ne, Ar, Kr, Xe, Rn

The **noble gases** are the most stable and unreactive elements in the periodic table. At room temperature, they are colourless, odourless gases (Figure 2.19). Some of the gases, such as argon and neon, are used in light fixtures. Some, such as neon, glow in distinctive colours. You may know that helium is lighter than air, and that is why helium balloons quickly float out of reach when released.

Figure 2.19 The noble gases are stable and unreactive. Argon is used inside the tubes of this energy-efficient fluorescent light bulb.

Reading Check

1. List three pieces of information besides an element's name and symbol that are recorded on a typical periodic table.
2. State how many protons are present in each of the following atoms: (a) silicon, (b) chromium, and (c) iodine.
3. List the following elements by atomic mass from lightest to heaviest: zinc, calcium, cobalt, nickel, carbon. Write the atomic mass beside each one.
4. What is the most common ion charge of chromium?
5. Where on the periodic table do you find the (a) metals, (b) non-metals, and (c) metalloids?

Explore More

Discovered in 1944, the element americium is used in a common household device that saves many lives every year. Find out more about this device and americium. Begin your research at **www.bcscience9.ca.**

2-2B The Modern Periodic Table

In this activity, you will use a simplified periodic table to discover the patterns of properties of elements.

The table below shows the general shape of a simplified periodic table. Elements are represented with symbols and are arranged in order of their atomic number. Also shown are gases, liquids, and solids at room temperature. Note that the colours of the blocks in the table indicate which elements are metals, non-metals, and metalloids.

gas = red
liquids = blue
solids = black

metals
metalloids
non-metals

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn

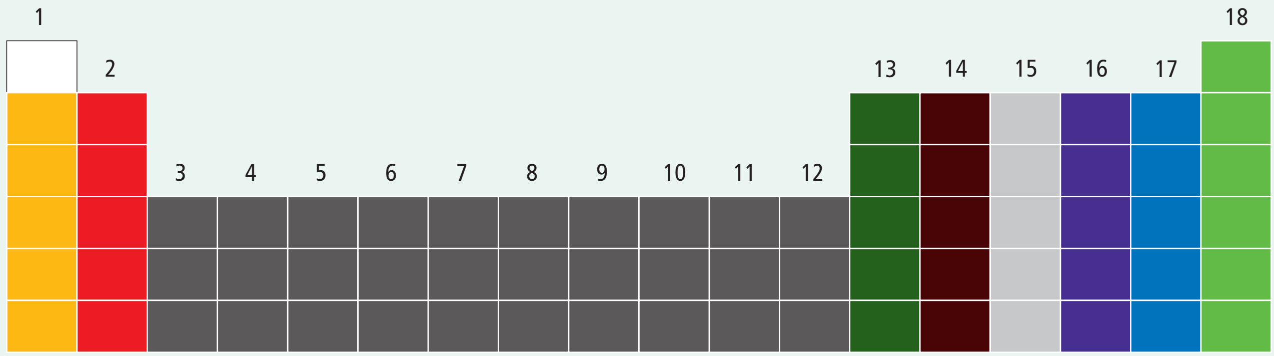
A simplified view of part of the modern periodic table

At first glance, it seems that the periodic table takes up unnecessary space. Would it not make more sense just to arrange the elements by increasing atomic number in a simple square grid?

H	He	Li	Be	B	C	N	O
F	Ne	Na	Mg	Al	Si	P	S
Cl	Ar	K	Ca	Sc	Ti	V	Cr
Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge
As	Se	Br	Kr	Rb	Sr	Y	Zr
Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd
In	Sn	Sb	Te	I	Xe	Cs	Ba
La	Hf	Ta	W	Re	Os	Ir	Pt
Au	Hg	Tl	Pb	Bi	Po	At	Rn

Listing elements in a grid

While a square grid may take up less space, chemists would not find such an arrangement very useful. The modern periodic table reflects an arrangement that puts similar elements close together. To understand why the periodic table is constructed the way it is and how to properly read it, you must know how chemists group elements according to their characteristics.



Groups in the periodic table

Chemists have identified families of elements that share similar properties. These families are grouped together in the periodic table in vertical columns. By creating such groups, chemists are better able to predict what properties elements will have. The groups and organization of the periodic table allowed them to correctly predict the characteristics of elements before they were even discovered.

The atomic number of an element helps determine its position in the periodic table. The numbering starts with the lowest atomic number 1 (hydrogen, H) and moves from left to right. The gaps in the table are skipped over, so the next element, with atomic number 2 (helium, He), goes in the top right corner. The next element, atomic number 3 (lithium, Li), starts at the left again underneath hydrogen.

What to Do

1. Make a copy of the simplified periodic table. Add the atomic numbers for hydrogen, helium, and lithium to your periodic table.
2. Using the previously described pattern, fill in the atomic numbers for the elements from carbon (C) to neon (Ne). It is not necessary to fill in numbers for the whole table.
3. Which element in each pair below has the larger atomic number? Explain how you know.
   (a) carbon (C) or silicon (Si)
   (b) silicon (Si) or phosphorus (P)
   (c) beryllium (Be) or sodium (Na)
4. There are 18 groups in the periodic table. Locate the elements in group 2 in your simplified periodic table. Record the symbols for these elements in a vertical list.
   (a) Which element in the list has the largest atomic number?
   (b) Which element would you expect to have the greatest atomic mass? Why?
5. List the symbols (and names wherever possible) of the other elements that are found in the same group as the elements below.
   (a) aluminum (Al)
   (b) potassium (K)
   (c) lead (Pb)
6. Locate the elements copper (Cu), silver (Ag), and gold (Au) on your simplified periodic table.
   (a) Are they in the same group?
   (b) Is this what you expected? Explain.
7. Review and compare the periodic table and grid methods of listing the elements. Explain why the periodic table is more useful to chemists than the grid.

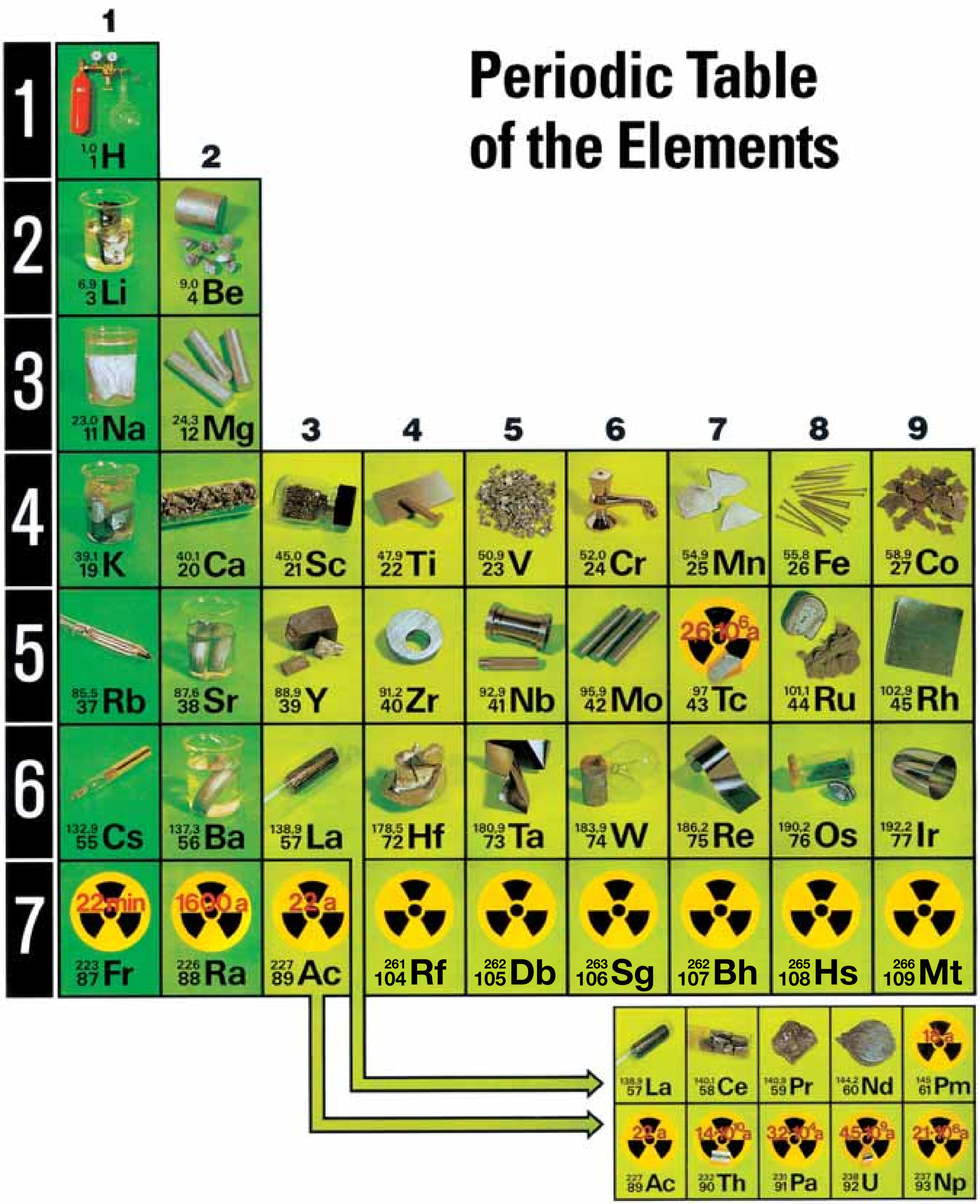
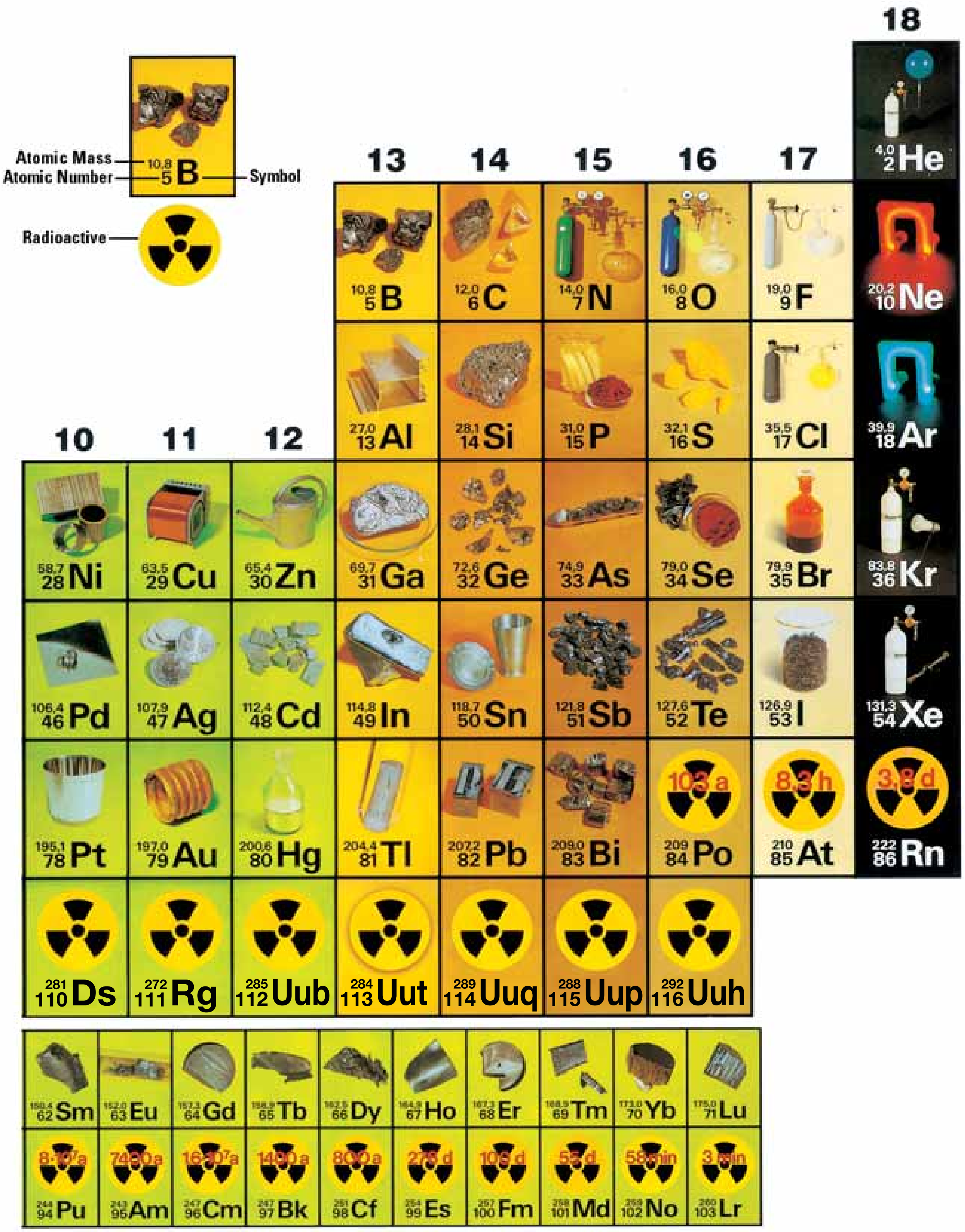


Figure 2.22 The periodic table shown here illustrates samples of the elements and common uses.



18
Atomic Mass
Atomic Number
10.8 5 B
Symbol
Radioactive
13
14
15
16
17
4.0 2 He
10.8 5 B
12.0 6 C
14.0 7 N
16.0 8 O
19.0 9 F
20.2 10 Ne
27.0 13 Al
28.1 14 Si
31.0 15 P
32.1 16 S
35.5 17 Cl
39.9 18 Ar
10
11
12
58.7 28 Ni
63.5 29 Cu
65.4 30 Zn
69.7 31 Ga
72.6 32 Ge
74.9 33 As
79.0 34 Se
79.9 35 Br
83.8 36 Kr
106.4 46 Pd
107.9 47 Ag
112.4 48 Cd
114.8 49 In
118.7 50 Sn
121.8 51 Sb
127.6 52 Te
126.9 53 I
131.3 54 Xe
195.1 78 Pt
197.0 79 Au
200.6 80 Hg
204.4 81 Tl
207.2 82 Pb
209.0 83 Bi
103 a
209 84 Po
8.3 h
210 85 At
3.8 d
222 86 Rn
281 110 Ds
272 111 Rg
285 112 Uub
284 113 Uut
289 114 Uuq
288 115 Uup
292 116 Uuh
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

Wild, Weird, Wonderful

www Science

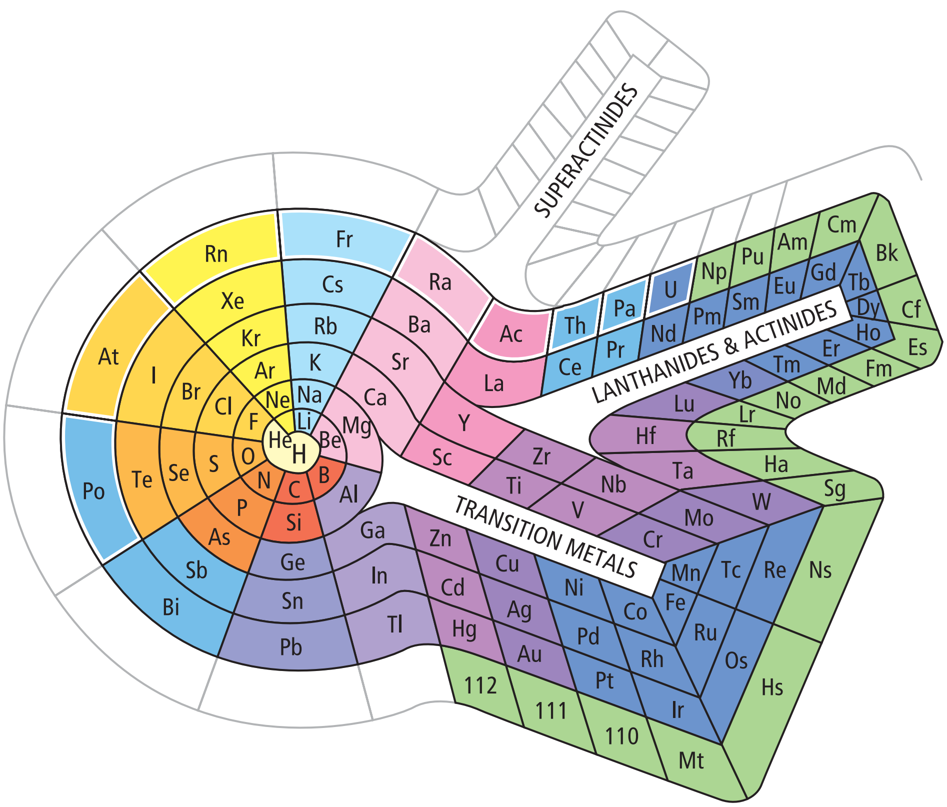
Peculiar Periodic Tables

You might not recognize the chart on this page as a periodic table, but it is. Look closely and you will see the symbols for all the elements. The colours identify the chemical families.

The periodic table that you have been using is the most common version, but it is not the only one. If you search the Internet for alternative periodic tables, you will find diamond-shaped tables, triangle-shaped ones, other spirals, and even 3-D tables. Designers of new periodic tables are looking for ways to improve the table to make it easier to see all the relationships among the elements.

The designer of this table wanted to emphasize the periods, so it has two periods of 8 elements, then two of 18 elements, then two of 32, and so on. The "arms" that stick out from the spiral are the lanthanides and actinides. These are the elements that you will find in those two rows down below the standard period table. In this spiral, they are connected with all the other elements.

Like Mendeleev's original periodic table, this table has an "empty" place for new elements. The design predicts that new elements will fit into the arm labelled "superactinides" that branches off between radium (Ra) and actinium (Ac). Not all scientists agree. Some think that new elements will be found between thorium (Th) and protactinium (Pa). Watch for discoveries of new elements to see who is right.



Dr. Theodor Benfey's spiral periodic table

Checking Concepts

1. What is the periodic table?
2. What information does the atomic number of an element reveal about the structure of the atoms of that element?
3. In the periodic table used today, are the elements listed in order of atomic number or atomic mass?
4. Use the periodic table on page 54 to find the atomic number for each of the following elements.
   (a) helium (b) oxygen (c) iron (d) gold (e) uranium (f) mendelevium
5. Which has more protons, an atom of sodium or an atom of potassium?
6. What does atomic mass measure?
7. The unit for atomic mass is the amu. What does each letter stand for?
8. What is the pattern in which atomic mass changes through the periodic table?
9. In the periodic table on page 54, find the atomic mass for each of the following elements:
   (a) lithium (b) silicon (c) iron (d) copper (e) mercury
10. Which has more mass, an atom of gold or an atom of lead?
11. What is meant by the term "ion charge"?
12. What particle has to be removed from an atom so that the atom becomes a positive ion?
13. (a) What kind of ions do elements on the left side of the periodic table form?
    (b) What kind of ions do elements on the right side of the periodic table form?
14. The common ion charge of some elements in the periodic table is zero. What does that tell you about the element?
15. Some elements in the periodic table have more than one ion charge shown. What does that tell you about these elements?
16. (a) What are three ion charges that an ion of manganese can have?
    (b) Which ion charge is the most common?
17. The elements in the periodic table may be classified as one of three types. What are the names of these types?
18. (a) List the names of four families in the periodic table.
    (b) Which are families of metals?
    (c) Which are families of non-metals?
19. From the periodic table on page 54, list five elements that are metalloids.
20. What are the horizontal rows in the periodic table called?
21. What are the vertical columns in the periodic table called?

Understanding Key Ideas

22. Which family of metals contains elements that are soft enough to cut with a knife?
23. Which family of metals is used in fireworks?
24. Which chemical family contains elements that at room temperature are solids, liquids, and gases?
25. List two properties of the elements in the noble gas family.
26. Explain the difference between atomic number and atomic mass.

Pause and Reflect

In this section you have learned how to make predictions about particular elements based on each element's position in the periodic table. This means it is possible to predict the properties of elements that have not yet been observed. For example, francium is so rare that there have never been enough atoms in one place for anyone to actually observe it. Still, you can predict several of its properties. What do you think would be some properties of francium, element number 87?