6.2 Classifying the Elements

Connecting to Your World
The sculptor Augustus Saint-Gaudens designed this gold coin at the request of Theodore Roosevelt. President Roosevelt wanted coins minted in the United States to be as beautiful as ancient Greek coins, which he admired. The coin is an example of a double eagle. The name derives from the fact that the coin was worth twice as much as $10 coins called eagles. A coin may contain a lot of information in a small space—its value, the year it was minted, and its country of origin. Each square in a periodic table also contains a lot of information. In this section, you will learn what types of information are usually listed in a periodic table.

Squares in the Periodic Table
The periodic table displays the symbols and names of the elements, along with information about the structure of their atoms. Figure 6.8 shows one square from the detailed periodic table of the elements in Figure 6.9 on page 162. In the center of the square is the symbol for sodium (Na). The atomic number for sodium (11) is above the symbol. The element name and average atomic mass are below the symbol. There is also a vertical column with the numbers 2, 8, and 1, which are the number of electrons in each occupied energy level of a sodium atom.

The symbol for sodium is printed in black because sodium is a solid at room temperature. In Figure 6.9, the symbols for gases are in red. The symbols for the two elements that are liquids at room temperature, mercury and bromine, are in blue. The symbols for some elements in Figure 6.9 are printed in green. These elements are not found in nature. In Chapter 25, you will learn what types of information are usually listed in a periodic table.

The background colors in the squares are used to distinguish groups of elements. For example, two shades of gold are used for the metals in Groups 1A and 2A. The Group 1A elements are called alkali metals, and the Group 2A elements are called alkaline earth metals. The name alkali comes from the Arabic al qali, meaning “the ashes.” Wood ashes are rich in compounds of the alkali metals sodium and potassium. Some groups of nonmetals also have special names. The nonmetals of Group 7A are called halogens. The name halogen comes from the combination of the Greek word hals, meaning salt, and the Latin word genesis, meaning “to be born.” There is a general class of compounds called salts, which include the compound called table salt. Chlorine, bromine and iodine, the most common halogens, can be prepared from their salts.

Guide for Reading

Key Concepts
- What type of information can be displayed in a periodic table?
- How can elements be classified based on their electron configurations?

Vocabulary
alkali metals
alkaline earth metals
halogens
noble gases
representative elements
transition metal
inner transition metal

Reading Strategy
Relating Text and Visuals
As you read, look carefully at Figure 6.9. After you read the section, explain what you can tell about an element from the color assigned to its symbol.

Figure 6.8 This is the element square for sodium from the periodic table in Figure 6.9. Interpreting Diagrams: What does the data in the square tell you about the structure of sodium atoms?

<table>
<thead>
<tr>
<th>Atomic number</th>
<th>Electrons in each energy level</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element name</th>
<th>Element symbol</th>
<th>Average atomic mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>22.990</td>
</tr>
</tbody>
</table>

Section Resources

Print
- Guided Reading and Study Workbook, Section 6.2
- Core Teaching Resources, Section 6.2 Review
- Transparencies, T67–T69
- Laboratory Manual, Lab 9

Technology
- Interactive Textbook with ChemASAP, Assessment 6.2
- Go Online, Section 6.2

Answers to...
Figure 6.8 There are 11 protons in the nucleus and 11 electrons in the three occupied energy levels.

6.2.1 Describe the information in a periodic table.
6.2.2 Classify elements based on electron configuration.
6.2.3 Distinguish representative elements and transition metals.

Guide for Reading

Build Vocabulary
LINCS Have students use the LINCS strategy. In LINCS exercises, students list what they know about each term, imagine a picture that describes the term, note a reminding “sound-alike” word, connect the terms to the sound-alike word by making up a short story, and then perform a brief Self-test.

Reading Strategy
Predict After students preview the section, have them predict the relationship between an element’s electron configuration and its position in the periodic table. Students can revise their predictions after they read the section.

INSTRUCT

Connecting to Your World
After students read the opening paragraph, have them volunteer other examples of small items that contain lots of information (e.g., train schedules, digital watch face, nutrient labels).

Squares in the Periodic Table

Use Visuals
Figure 6.8 Remind students what average atomic mass represents. Make sure students understand the vertical column of numbers.
Section 6.2 (continued)

Use Visuals

Figure 6.9 Have students examine the periodic table and find the types of information that the table provides. Summarize suggestions on the board. Examples include element name, atomic number, average atomic mass, and physical state at atmospheric pressure and room temperature.

Discuss

Have students examine the periodic table and determine the accuracy of this statement: Atomic mass always increases as atomic number increases. *(The trend is generally true, but there are exceptions. For example, the atomic numbers of Co, Ni, and Cu increase by one unit (27, 28, 29), but Ni has the lowest average atomic mass of these three elements.)*

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**Facts and Figures**

**Element Nomenclature**

Names suggested by those who create new elements must be approved by the International Union of Pure and Applied Chemistry (IUPAC). The process can be lengthy. For example, the names chosen for elements 104–108 by the nomenclature committee of IUPAC in 1994 were not those endorsed by the American Chemical Society (ACS). After years of negotiation, a compromise resulted in the names that appear in the periodic table. Elements beyond 111 have been discovered but are not yet named. Element 110 was discovered in 1994 by a team of scientists in Darmstadt, Germany. The IUPAC Council voted formal approval of the name darmstadtium (Ds) on August 16, 2003.
Handbook. Nutrients on page R45 of the Elements can begin with the discussion of micro-nutrients. Have students do research on such elements as copper, chromium, iodine, and manganese to find out more about their biological roles. They can begin with the discussion of micro-nutrients on page R45 of the Elements Handbook.

Section 6.2 Classifying the Elements

The Periodic Table

*Name not officially assigned.
Electron Configurations in Groups

Discuss

Lead a class discussion on electron configurations of noble gases and representative elements. Select some elements and have students write out the electron configurations for those elements. Have students compare the electron configurations for all the elements in a single group. Ask students to identify similarities. (Noble gases are sometimes classified as representative elements because they are in the p block of elements.)

FYI

The term valence electron will be introduced in Chapter 7.

Electron Configurations in Groups

Electrons play a key role in determining the properties of elements. So there should be a connection between an element’s electron configuration and its location in the periodic table.

Elements can be sorted into noble gases, representative elements, transition metals, or inner transition metals based on their electron configurations. You may want to refer to Figure 6.9 as you read about these classes of elements.

The Noble Gases

The blimp in Figure 6.10 is filled with helium. Helium is an example of a noble gas. The noble gases are the elements in Group 8A of the periodic table. These nonmetals are sometimes called the inert gases because they rarely take part in a reaction. The electron configurations for the first four noble gases in Group 8A are listed below.

- Helium (He) \(1s^2\)
- Neon (Ne) \(1s^22s^22p^6\)
- Argon (Ar) \(1s^22s^22p^63s^23p^6\)
- Krypton (Kr) \(1s^22s^22p^63s^23p^63d^{10}4s^24p^6\)

Look at the description of the highest occupied energy level for each element, which is highlighted in yellow. The s and p sublevels are completely filled with electrons. Chapter 7 will explain how this arrangement of electrons is related to the relative inactivity of the noble gases.

The Representative Elements

Figure 6.11 shows the portion of the periodic table containing Groups 1A through 7A. Elements in these groups are often referred to as representative elements because they display a wide range of physical and chemical properties. Some are metals, some are nonmetals, and some are metalloids. Most of them are solids, but a few are gases at room temperature, and one, bromine, is a liquid.

In atoms of representative elements, the s and p sublevels of the highest occupied energy level are not filled. Look at the electron configurations for lithium, sodium, and potassium. In atoms of these Group 1A elements, there is only one electron in the highest occupied energy level. The electron is in an s sublevel.

- Lithium (Li) \(1s^22s^1\)
- Sodium (Na) \(1s^22s^22p^63s^1\)
- Potassium (K) \(1s^22s^22p^63s^23p^64s^1\)

In atoms of carbon, silicon, and germanium, in Group 4A, there are four electrons in the highest occupied energy level.

- Carbon (C) \(1s^22s^22p^2\)
- Silicon (Si) \(1s^22s^22p^63s^23p^2\)
- Germanium (Ge) \(1s^22s^22p^63s^23p^63d^{10}4s^24p^2\)

For any representative element, its group number equals the number of electrons in the highest occupied energy level.

**Checkpoint** Why are noble gases sometimes referred to as inert gases?
Magnesium This magnified view of a leaf shows the green structures where light energy is changed into chemical energy. The compound chlorophyll, which contains magnesium, absorbs the light.

Sodium When salt lakes evaporate, they form salt pans like this one in Death Valley, California. The main salt in a salt pan is sodium chloride.

Sulfur These scientists are sampling gases being released from a volcano through a vent called a fumarole. The yellow substance is sulfur.

Arsenic This bright red ore is a major source of arsenic in Earth’s crust. It contains a compound of arsenic and sulfur.

TEACHER Demo

Differences in Reactivity of Metals

Purpose Students observe differences in the reactivity of magnesium, tin, and copper.

Materials 0.2M HCl; 6 large test tubes; test tube rack; small pieces of clean magnesium, tin, and copper; matches; wood splint

Safety Wear goggles for this demo.

Procedure Place three large test tubes in a test tube rack. To each test tube, add a small, clean piece of a different metal—magnesium, tin, and copper. Carefully add some of the 0.2M HCl to each test tube and invert a test tube over it. Point out the appearance of bubbles. After a while, carefully ignite the hydrogen in the inverted test tube from the magnesium or tin reaction.

Expected Outcome The magnesium and tin react with the HCl, producing hydrogen. The hydrogen ignites with an explosive pop. The copper shows no sign of reaction.

Answers to...

Figure 6.10 Helium is less dense than air.

Checkpoint They rarely take part in a reaction.
Transition Elements

**Lanthanides in Consumer Products**
Have students use the library or Internet to compile a list of consumer products that contain lanthanides or require lanthanides for processing.

**Discuss**
Students may think that elements whose names are familiar are always more abundant than less familiar elements. You can use the following data to show why calling inner transition metals “rare-earth elements” is misleading. In Earth’s crust, there is 1.7 ppb of osmium, 37 ppb of platinum, 67 ppb of mercury, 1700 ppb of tantalum, 6000 ppb of thorium, 10,000 ppb of lead, 60,000 ppb of cerium, and 34,000 ppb of lanthanum.

**Use Visuals**

**Figure 6.12** Emphasize the relationship between the position of an element in the periodic table and the element’s atomic structure. Ask, What do all the elements in Group 1A have in common? (They all have one electron in the s orbital in the highest occupied energy level.) What do all the elements in Group 3A have in common? (They all have one electron in a p orbital in the highest occupied energy level.) To help students understand the instructions for writing electron configurations for elements in the d and f blocks, review the aufbau diagram in Figure 5.7 on p. 133.

Transition Elements

In the periodic table, the B groups separate the A groups on the left side of the table from the A groups on the right side. Elements in the B groups, which provide a connection between the two sets of representative elements, are referred to as transition elements. There are two types of transition elements—transition metals and inner transition metals. They are classified based on their electron configurations.

The transition metals are the Group B elements that are usually displayed in the main body of a periodic table. Copper, silver, gold, and iron are transition metals. In atoms of a transition metal, the highest occupied s sublevel and a nearby d sublevel contain electrons. These elements are characterized by the presence of electrons in d orbitals.

The inner transition metals appear below the main body of the periodic table. In atoms of an inner transition metal, the highest occupied s sublevel and a nearby f sublevel generally contain electrons. The inner transition metals are characterized by f orbitals that contain electrons. Before scientists knew much about inner transition metals, people began to refer to them as rare-earth elements. This name is misleading because some inner transition metals are more abundant than other elements.

**Blocks of Elements** If you consider both the electron configurations and the positions of the elements in the periodic table, another pattern emerges. In Figure 6.12, the periodic table is divided into sections, or blocks, that correspond to the highest occupied sublevels. The s block contains the elements in Groups 1A and 2A and the noble gas helium. The p block contains the elements in Groups 3A, 4A, 5A, 6A, 7A, and 8A, with the exception of helium. The transition metals belong to the d block, and the inner transition metals belong to the f block.

You can use Figure 6.12 to help determine electron configurations of elements. Each period on the periodic table corresponds to a principal energy level. Say an element is located in period 3. You know that the s and p sublevels in energy levels 1 and 2 are filled with electrons. You read across period 3 from left to right to complete the configuration. For transition elements, electrons are added to a d sublevel with a principal energy level that is one less than the period number. For the inner transition metals, the principal energy level of the f sublevel is two less than the period number. This procedure gives the correct electron configurations for most atoms.

![](image)

**Differentiated Instruction**

**Less Proficient Readers**
Divide the class into small groups. Have each group write electron configurations for an s-block element, a p-block element, a d-block element, and an f-block element. Don’t assign any of the d-block elements with unpredictable configurations. Ask students to explain the method they used to determine specific electron configurations.
CONCEPTUAL PROBLEM 6.1

Using Energy Sublevels to Write Electron Configurations

Nitrogen is an element that organisms need to remain healthy. However, most organisms cannot obtain nitrogen directly from air. A few organisms can convert elemental nitrogen into a form that can be absorbed by plant and animal cells. These include bacteria that live in lumps called nodules on the roots of legumes. The photograph shows the nodules on a bean plant. Use Figure 6.12 to write the electron configuration for nitrogen (N), which has atomic number 7.

1. **Analyze** Identify the relevant concepts.
   For all elements, the atomic number is equal to the total number of electrons. For a representative element, the highest occupied energy level is the same as the number of the period in which the element is located. From the group in which the element is located, you can tell how many electrons are in this energy level.

2. **Solve** Apply concepts to this situation.
   Nitrogen is located in the second period of the periodic table and in the third group of the $p$ block. Nitrogen has seven electrons. Based on Figure 6.12, the configuration for the five electrons in the first energy level is $1s^2$. The configuration for the five electrons in the second energy level is $2s^22p^3$.

### Practice Problems

8. Use Figure 6.9 and Figure 6.12 to write the electron configurations of the following elements.
   - a. carbon
   - b. strontium
   - c. vanadium
   *(Hint: Remember that the principal energy level number for elements in the $d$ block is always one less than the period number.)*

9. List the symbols for all the elements whose electron configurations end as follows. Each $n$ represents an energy level.
   - a. $n^2n^2$
   - b. $n^2n^p$
   - c. $ns^2nd^2$

### 6.2 Section Assessment

10. **Key Concept** What information can be included in a periodic table?
11. **Key Concept** Into what four classes can elements be sorted based on their electron configurations?
12. Why do the elements potassium and sodium have similar chemical properties?
13. Classify each element as a representative element, transition metal, or noble gas.
   - a. $1s^22s^22p^63s^23p^64s^24p^6$
   - b. $1s^22s^22p^63s^23p^63d^104s^24p^6$
   - c. $1s^22s^22p^63s^23p^63d^10$
14. Which of the following elements are transition metals: Cu, Sr, Cd, Au, Al, Ge, Co?
15. How many electrons are in the highest occupied energy level of a Group 5A element?

**Elements Handbook**

**Noble Gases** Look at the atomic properties of noble gases on page R36. In a gas discharge tube, what color light is produced by each noble gas? Use what you know about the structure of atoms to explain why the color is different for each gas.

**Interactive Textbook**

Assessment 6.2 Test yourself on the concepts in Section 6.2.

with ChemASAP

### Section 6.2 Assessment

10. symbols and names of the elements; atomic number and average atomic mass; information about electron configuration
11. representative elements, noble gases, transition metals, and inner transition metals
12. They are in the same group and have the same number of electrons in the highest occupied energy level.
13. a. noble gas
   - b. transition metal
   - c. representative element
14. Cu, Cd, Au, Co
15. 5

### Answers

8. a. $1s^22s^22p^2$
   - b. $1s^22s^22p^63s^23p^64s^24p^6$
   - c. $1s^22s^22p^63s^23p^63d^34s^2$
9. a. B, Al, Ga, In, Tl
   - b. F, Cl, Br, I, At
c. Ti, Zr, Hf, Rf

### Practice Problems Plus

Chapter Review problems 34 and 35 are related to Conceptual Problem 6.1.

### Evaluate Understanding

**ASSESS**

Call out pairs of elements in the same group and have students write their electron configurations. This activity can be made into a game where groups compete with other groups to come up with the answer first. Students should eventually be able to write the electron configurations quickly.

**Reteach**

To reinforce the relationship between configurations and position in the periodic table, provide configurations and ask students to identify and locate the elements. Ask students to explain which parts of a configuration proved most useful for determining the identity.

**Interactive Textbook**

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 6.2.

with ChemASAP

**Answers to...**

Figure 6.12 five
True Colors

Purpose
The connection of this Technology & Society to Chapter 6 content may not be immediately obvious. It presents an important application of transition metals. Many pigments depend on the tendency of most transition metals to form colored compounds.

Background
Paint is used to cover or hide a surface to which it is applied, decorate a surface, or protect a surface. Egg yolk (in egg tempera paint), gum Arabic (in water colors and gouache), and linseed oil (oil paint) are examples of binders. Many pigments depend on the tendency of transition metals to form colored compounds.

The bison painting is from the Altamira Caves in Spain (about 12,000 B.C.). Although the oldest known paintings are about 35,000 years old, archaeologists in Zambia found pigments and paint grinding equipment that were between 350,000 and 400,000 years old. Some prehistoric artists chemically altered pigments before applying them to cave walls. About one quarter of the samples from Troubat Cave in the Pyrenees were heated in an open fire.

Paint consists essentially of a pigment, a binder, and a liquid in which the other components are dissolved or dispersed. The liquid keeps the mixture thin enough to flow. The binder attaches the paint to the surface being painted, and the pigment determines the color. Pigments may be natural or manufactured. They may be inorganic or organic. The same pigment can be used in a water-based or oil-based paint. Comparing and Contrasting Describe at least three differences between the cave painting and the painting by Jacob Lawrence.

Natural pigments A prehistoric artist had a limited choice of colors—black from charcoal and red, brown, and yellow from oxides of iron in Earth’s crust. These oxides (or ochre) pigments are often referred to as earth tones.

Prehistoric art Around 14,000 years ago, an artist painted this bison on the ceiling of a cave in Spain. It is about two meters long.

Charred wood is a source of charcoal.
From pigments to paint

Artists mixed manufactured pigments with binders and solvents to make paint. Although premixed paints became available around 1800, some artists, including Jacob Lawrence, continued to mix their own paints.

Manufactured pigments

Alchemists (and the Chemists) made pigments that don’t exist in nature. They also made purer versions of natural pigments. Many of these pigments contain transition metals.

Manufacturers agreed to list both common pigment names and color index codes on labels. See the table below for the composition and codes for the pigments shown on p. 169.

<table>
<thead>
<tr>
<th>Pigment</th>
<th>Formula</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red iron oxide</td>
<td>iron(III) oxide, Fe₂O₃</td>
<td>PR 101</td>
</tr>
<tr>
<td>Cadmium orange</td>
<td>solid solution of cadmium selenide, CdSe, and cadmium sulfate, CdSO₄</td>
<td>PO 20</td>
</tr>
<tr>
<td>Cobalt yellow</td>
<td>potassium cobalt nitrite, K₃[Co(NO₂)₆]·H₂O</td>
<td>PY 40</td>
</tr>
<tr>
<td>Zinc white</td>
<td>zinc oxide, ZnO</td>
<td>PW 4</td>
</tr>
<tr>
<td>Chromium oxide green</td>
<td>chromiu(III) oxide, Cr₂O₃</td>
<td>PG 17</td>
</tr>
<tr>
<td>Cobalt blue</td>
<td>cobalt(II) aluminate, Co(AlO₂)₂</td>
<td>PB 28</td>
</tr>
<tr>
<td>Manganese violet</td>
<td>manganese ammonium pyrophosphate, Mn(III)NH₄P₂O₇</td>
<td>PV 16</td>
</tr>
</tbody>
</table>

Coding Scheme for Paints

Because pigments with the same common name can contain different substances, the Society of Dyers and Colourists in London and the American Association of Textile Chemists and Colorists established a standard coding scheme for pigments. Manufacturers agreed to list both common pigment names and color index codes on labels. See the table below for the composition and codes for the pigments shown on p. 169.

Answers to...
Comparing and Contrasting

Possible differences include the subject matter, the range of colors, and the anonymity of the artist who painted in the cave.