

## TOPIC 2.3

# How can atomic theory explain patterns in the periodic table?

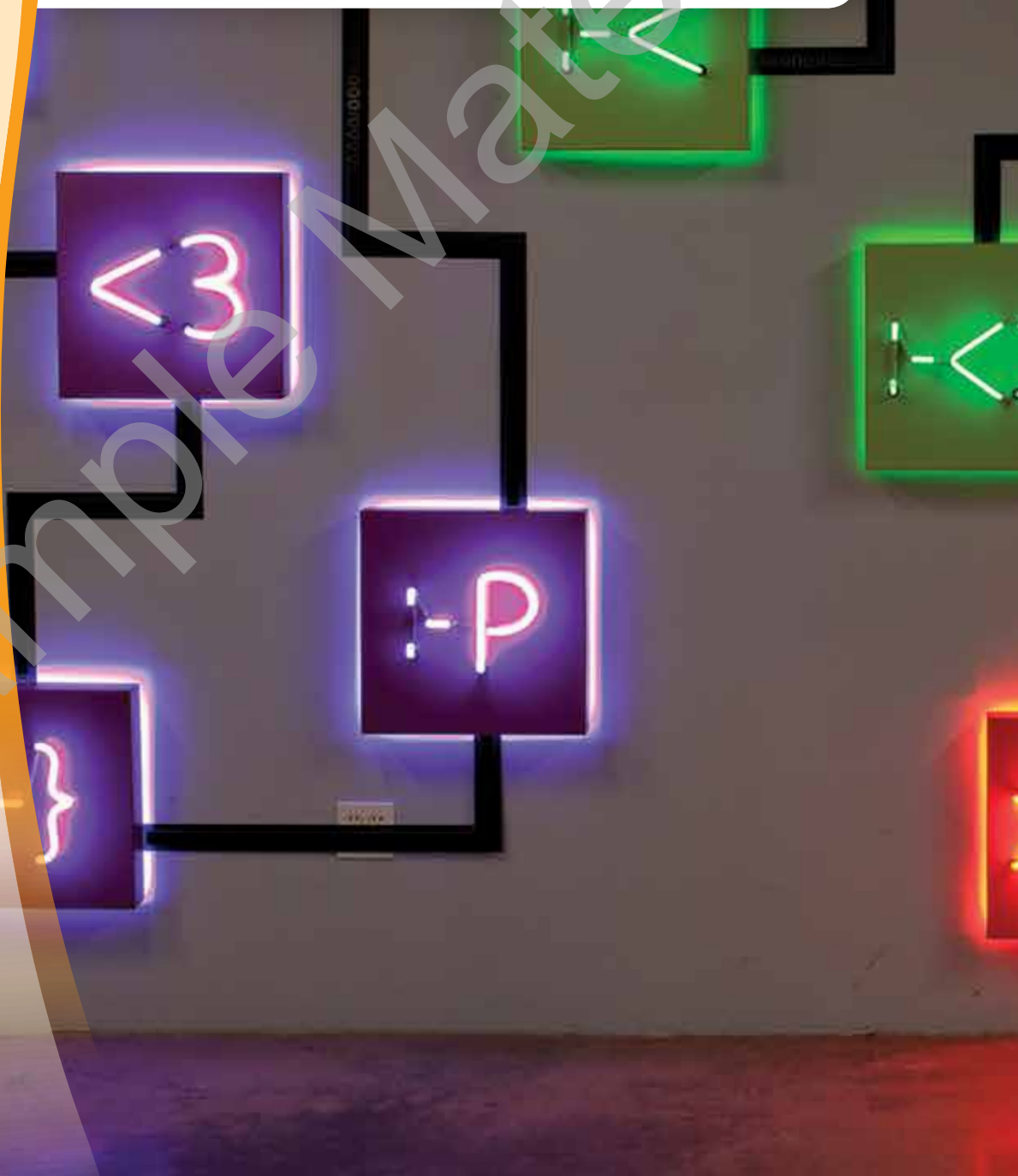
### Key Concepts

- The structure of atoms can be represented using simple diagrams.
- Elements in chemical groups have similar electron arrangements.
- The periodic table shows how properties of elements change in predictable ways.

### Curricular Competencies

- Seek and analyze patterns, trends, and connections in data, including describing relationships between variables (dependent and independent) and identifying inconsistencies.
- Construct, analyze, and interpret graphs, models, and/or diagrams.
- Formulate physical or mental theoretical models to describe a phenomenon.

**T**his playful sculpture by artist Lisa Schulte is called *A Conversation*. Schulte used neon and argon lights to create a trail of emojis that tell a story. In contrast to the increasingly strong emotional “reactions” portrayed here, noble gases such as neon and argon are inert—they do not undergo chemical reactions. The inertness of noble gases is one example of a pattern revealed by the periodic table. But what causes these patterns?



# Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Identifying Preconceptions** Atoms are made up of subatomic particles. Electrons are negatively charged, protons are positively charged, and neutrons have no charge. How do these particles affect one another in the atom? How do forces between charged particles affect chemical properties?
2. **Questioning** What causes the different colours in lights like the ones shown in the photo? Why are noble gases used in lights of this type? How are neon lights made and what causes them to glow?
3. **Communicating** The light sculpture shown uses emojis to create an artistic effect. Can emojis be used to model the periodic table? Select at least 10 emojis and make a meaningful arrangement of them in columns and rows. Write a brief blog post to explain your arrangement.
4. **Applying First Peoples Perspectives** Investigate the work of First Nations artist Kevin McKenzie, who combines neon lighting, chrome, and other modern materials with traditional materials. What are some effects of using materials and techniques of two cultures?



## Key Terms

There are four key terms that are highlighted in bold type in this Topic:

- valence shell
- valence electrons
- ion
- periodic trend

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

# The structure of atoms can be represented using simple diagrams.

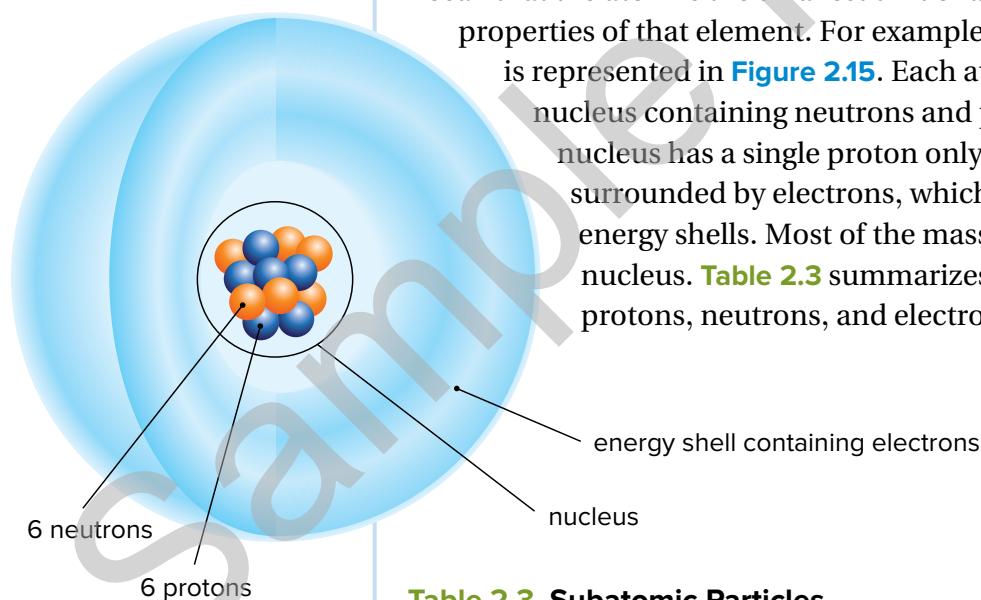
## Activity

### What do you know about atoms?

In your notebook, and without referring to your textbook, draw a diagram of a helium atom. What information did you provide about the atom in your diagram?



**Figure 2.15** Every carbon atom has six positively charged protons in its nucleus and six negatively charged electrons surrounding the nucleus. (Most carbon atoms have six neutrons, but some have seven or eight.)



Mendeleev arranged elements in his periodic table based on the physical and chemical properties of different elements. Metals appear on the left side of the zigzag line, and non-metals appear on the right. Elements in the same families share similar properties. But why is this the case? What characteristic of elements causes their properties to repeat in this predictable way? To find the answer, we need to consider the structure of the atom.

## Key Features of Atomic Structure

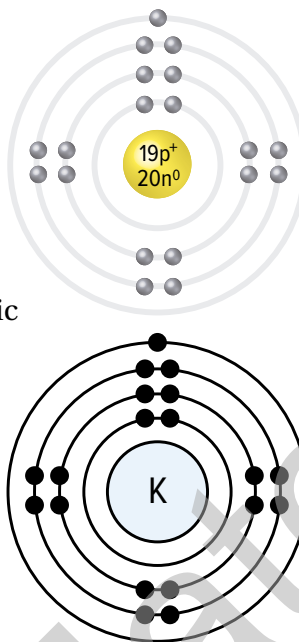
Recall that the atom is the smallest unit of an element that has the properties of that element. For example, an atom of carbon is represented in **Figure 2.15**. Each atom has a tiny, dense nucleus containing neutrons and protons. (A hydrogen nucleus has a single proton only.) The nucleus is surrounded by electrons, which exist in specific electron energy shells. Most of the mass of an atom is in the nucleus. **Table 2.3** summarizes key characteristics of protons, neutrons, and electrons.

**Table 2.3** Subatomic Particles

Name	Relative Mass	Electric Charge	Symbol	Location in Atom
proton	1836	+	$p^+$	nucleus
neutron	1837	0	$n^0$	nucleus
electron	1	—	$e^-$	electron energy shells surrounding the nucleus

## Bohr Diagrams Are a Useful Way to Model Atoms

It is useful to be able to represent atoms in a simplified, two-dimensional way that provides information about their structure. Bohr diagrams represent the electron arrangements of atoms using the “energy shell” concept of Bohr’s model of the atom. As shown in **Figure 2.16**, a Bohr diagram shows how many electrons occupy each specific energy level or shell. The number of electrons that can occupy each energy shell changes as you move outward from the nucleus. The first energy shell can have a maximum of two electrons. The second and third energy shells can have a maximum of eight electrons. (This is true for the first 20 elements, after which things become more complex.) The outermost occupied shell of an atom is called a **valence shell**. Electrons in the valence shell are called **valence electrons**.



**Figure 2.16** Both of these Bohr diagrams represent an atom of potassium. **What is one drawback and one advantage of each diagram?**

**valence shell** the outermost occupied energy shell of an atom

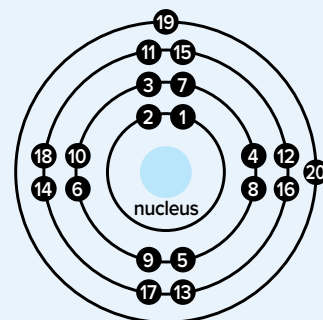
**valence electrons** the electrons in the outermost occupied energy shell of an atom

### Activity

#### Model Bohr Atoms

Your teacher will assign you a number from one to 20. Using a pie plate, a marker, construction paper, pom-poms, and glue, create a Bohr diagram for the element that corresponds to your number. For example, if you are number 6, your element is carbon.

1. Glue a construction paper circle “nucleus” in the centre of your pie plate. Write the symbol for your element on the circle.
2. Examine the diagram on the right to see in what order you will place the pom-pom “electrons” and how many shells will be occupied. (For a neutral atom, number of electrons = atomic number.)
3. Draw circles on the pie plate to represent the occupied energy shells for your atom. Then glue on pom-poms to represent your electrons.
4. Display your model. In your notebook, use the models to help you draw Bohr diagrams for each of the first 20 elements.



### Before you leave this page . . .

1. Draw a diagram of an atom, labelling protons, electrons, and neutrons.
2. List how many electrons can be found in the first and second energy shells.

# Elements in chemical groups have similar electron arrangements.

## Activity

### Valence Electrons and Group Numbers

Examine **Figure 2.17**. How do the valence electrons in each group relate to the group number?



**Figure 2.17** shows Bohr diagrams for elements in the first three periods of the periodic table. If you look carefully at the electron arrangements, you will see that two key patterns emerge:

1. *Atoms in the same group have the same number of valence electrons.* Each element in Group 1 has one valence electron, and each element in Group 2 has two valence electrons. The elements in Groups 13 to 18 have 3, 4, 5, 6, 7, and 8 valence electrons, respectively. An exception is helium. Helium has only two valence electrons, but the other noble gases have eight.
2. *Atoms in the same period have the same number of occupied energy shells.* The two elements in the first period, hydrogen and helium, have only one occupied energy shell. The eight elements in the second period have two occupied energy shells. The eight elements in the third period have three.

**Figure 2.17** Analyzing the electron arrangements of elements in the same group or period can help explain differences and similarities in the properties of the elements.

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



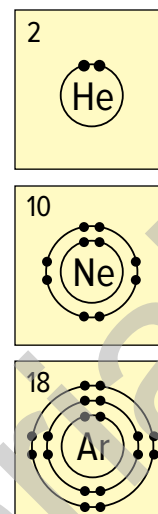
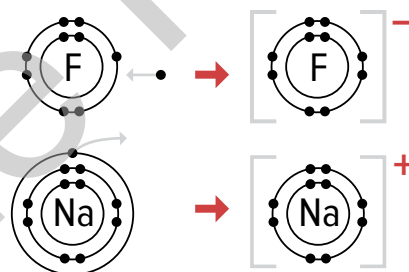
## Noble Gas Stability: A Full Valence Shell

During a chemical reaction, atoms gain, lose, or share valence electrons with other atoms. Noble gases are special among the elements, because they all have full valence shells. This feature makes them unusually stable. Their atoms do not tend to gain, lose, or share electrons with other elements—for the most part, they are unreactive. As you can see in **Figure 2.18**, helium has two electrons, which is the maximum number of electrons for the first energy shell. The other noble gases have eight electrons in their valence shells.

## How Other Elements Achieve Full Valence Shells

One way that atoms of elements other than the noble gases can achieve a full valence shell is by gaining or losing electrons during chemical reactions. When a neutral atom gains or loses an electron, it becomes charged—it becomes an **ion**. When an atom loses an electron, it becomes a positively charged ion. When an atom gains an electron, it becomes a negatively charged ion.

The reactivity of an element is linked to how close it is to having a full valence shell. For this reason, the most reactive elements are those of Groups 1 and 17. The atoms of these elements are only one electron away from having a full set of valence electrons. As shown in **Figure 2.19**, Group 1 atoms can give up an electron, exposing the full energy shell underneath. Group 17 atoms can gain an electron, completing their valence shell.



**Figure 2.18** The noble gases have full valence shells.

**ion** an atom with a positive or negative charge

**Figure 2.19** If a fluorine atom gains an electron, forming the ion  $F^-$ , it will have the same electron arrangement as neon, including a full valence shell. A sodium atom can have the same electron arrangement as neon by losing an electron and forming the ion  $Na^+$ .

## Extending the Connections

### A Noble Gas is Hard to Find

When Mendeleev developed his periodic table, he did not include a column for the noble gases, because they had not yet been discovered. Which noble gas was found first and how was it discovered? Who realized where the noble gases should be placed on the periodic table? Do research to find out.

### Before you leave this page . . .

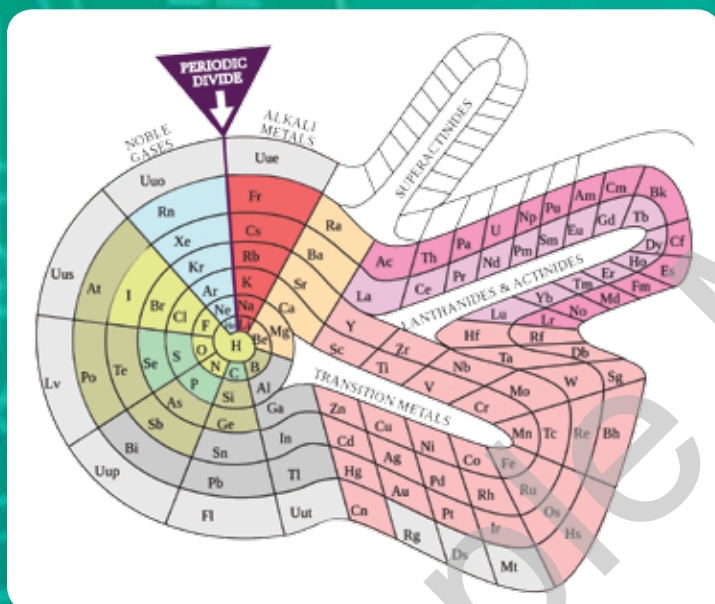
1. Explain why metals tend to lose electrons and non-metals tend to gain them.
2. Use diagrams to compare the electron arrangements of a chloride ion, a potassium ion, and an argon atom.

# AT ISSUE

## How can the periodic table be represented in a different form?

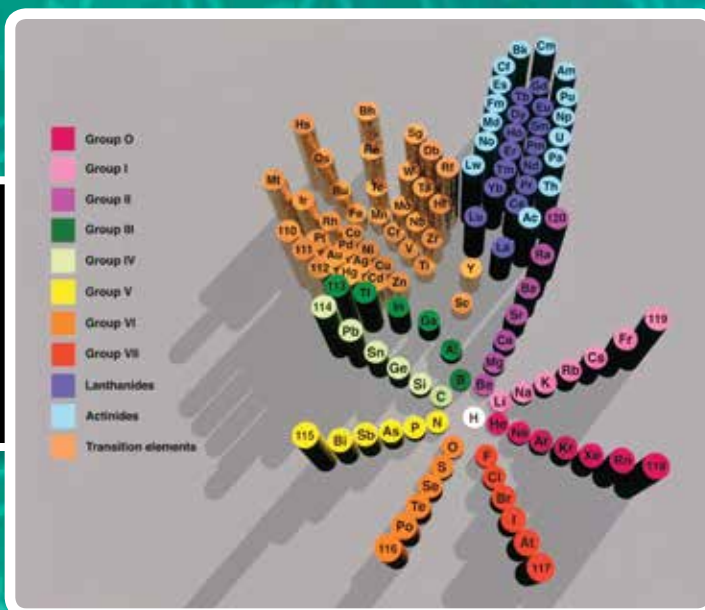
### What's the Issue?

The modern periodic table that you have been learning about is organized in columns and rows according to the atomic numbers of the elements. When the elements are arranged in order of increasing atomic number, a periodic pattern in the properties of the elements emerges.

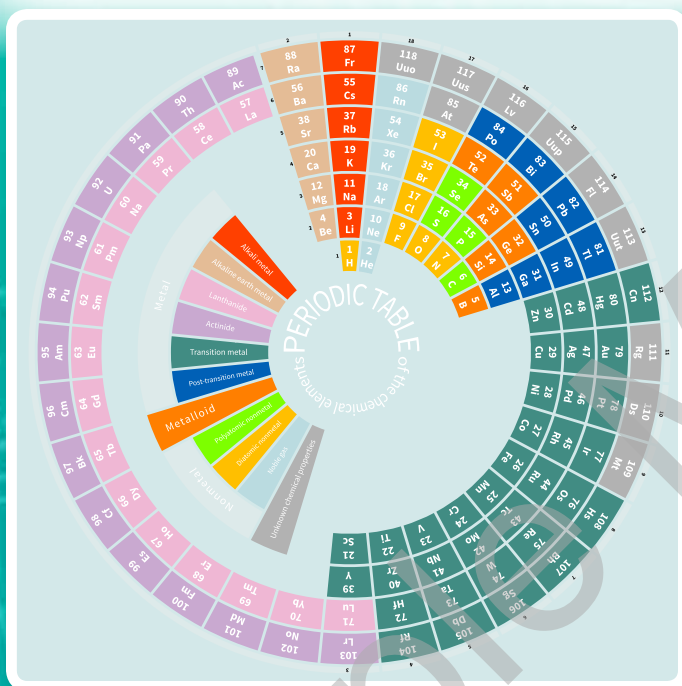


Dr. Theodor Benfey designed this spiral periodic table in 1964. One of his aims was to show the continuity of the elements and remove the apparent “jump” from one period to the next that occurs in the traditional periodic table.

In this three-dimensional digital periodic table, the heights of the columns represent the magnitude of the atomic numbers of the elements.



But is that the only way that all the elements could be organized? Many people have argued no—and have developed their own versions of the periodic table. In fact, since the early 1900s more than 300 versions of the periodic table have been developed. Some tables have been developed purely for creative reasons. Others have been developed to show different types of information or relationships between elements and their properties that the standard version of the periodic table does not show.



Like Dr. Benfey's spiral table, this circular periodic table emphasizes the continuity between periods. However, its shape is simpler and it uses only colour-coding to show the groups.

This three-dimensional periodic spiral was designed in 1977 by Dr. Hinsdale Bernard. The connected platforms represent the periods, and the elements are colour-coded to show what part of the table they belong to.



## Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. What key pieces of information do you think should be in a periodic table?
2. Choose one of the periodic tables shown on these pages to learn more about, or choose another table to research, such as an online

interactive table. Why did the designer of your chosen table choose to present it that way? What other questions do you have about the table? Perform research to find the answers to your questions.



## CONCEPT 3

# The periodic table shows how properties of elements change in predictable ways.

### Activity

#### On Trend

What does the term *trend* mean to you? Write a brief definition. How have you seen the term used in the news media and on social media? How is your life influenced or affected by trends?



**periodic trend** a regular variation in the properties of elements based on their atomic structure

In chemistry, the term **periodic trend** refers to a regular variation in the properties of elements based on their atomic structure. The periodic table is a powerful tool for analyzing such trends because it can help you see and compare variations in groups and periods. One trend that can be analyzed in this way is atomic size.

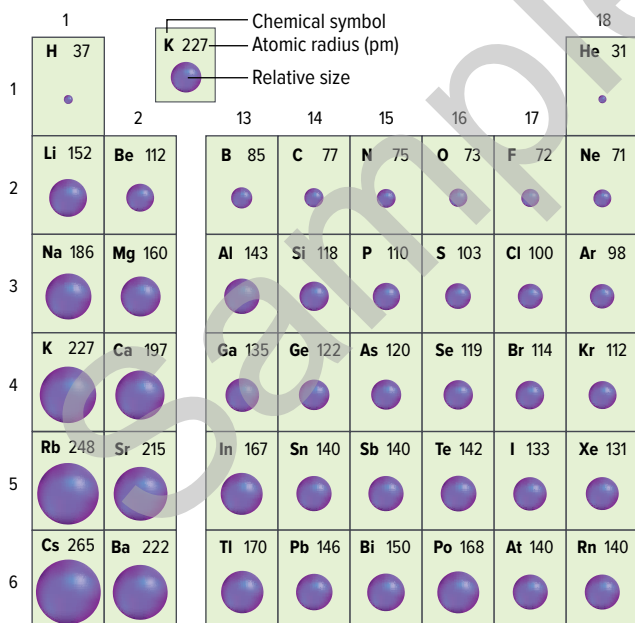
### Atomic Size Trends

**Figure 2.20** compares the sizes of atoms of each main-group element. Observe the sizes of the atoms in each group and period.

1. *Atomic size increases moving down a group.* As you move down a group in the periodic table, elements have atoms with increasing

numbers of energy shells. The greater the number of shells, the farther the valence electrons are from the nucleus, and therefore the larger the atom is.

2. *Atomic size decreases moving left to right across a period.* Elements have increasing numbers of electrons in their valence shells as you move left to right across a period. And yet the atomic size *decreases*. Why? As you move from left to right in a period, the number of occupied valence shells stays the same, but the number of protons in the nucleus increases. The attraction between each valence electron and the nucleus increases because a greater positive charge on the nucleus pulls more strongly on the negatively charged electrons. As a result, the valence electrons are pulled more tightly towards the nucleus.



**Figure 2.20** Atomic size is represented here by the sizes of the spheres. The number under each element is the radius of the atom in picometres (pm). One picometre is equal to 1/1 000 000 000 000 m.

## Metal Reactivity and Atom Size

**Figure 2.21** compares what happens when potassium and sodium are added to water. As you can see, the reaction is more vigorous and violent for the potassium. In other words, potassium is more reactive than sodium. Why is this the case? They are both in Group 1, and both have one valence electron. The difference is that a potassium atom is larger than a sodium atom. A potassium atom's valence electron is farther away from the nucleus than the sodium atom's valence electron. As a result, the pull of the nucleus is weaker, and the electron is easier to remove. That is what makes potassium more reactive.

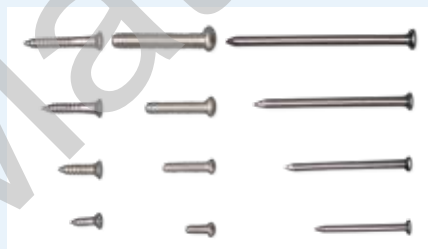


**Figure 2.21** Potassium **A** is more reactive than sodium **B** because less energy is needed to remove the valence electron from potassium.

### Activity

#### Recognizing Trends

The periodic table makes it easy to see trends in atomic properties such as atomic size. Can you use a similar arrangement to reveal trends in the characteristics of everyday objects?



1. Obtain a sample of fasteners, including nails, bolts, and screws.
2. Measure the length of each nail with a ruler.
3. Use a balance to measure the mass of each nail.
4. Place the nails in a series from smallest to largest.
5. Continue to arrange a series of screws and a series of bolts that also correspond to the series of nails created in Step 4.
6. Make a table listing the length and mass of each fastener according to its position.
7. Describe the following:
  - a) the trend in mass as you go from left to right across each row
  - b) the trend in mass as you go down each column of the table
8. Analyze your organization of the fasteners, and explain any other trends that you find in the table.
9. Describe how you could make a similar “periodic table” of another type of familiar item.



### Before you leave this page . . .

1. Explain why atoms get larger down a group on the periodic table.
2. Explain why atoms get smaller from left to right across a period on the periodic table.
3. Explain why an alkali metal is more reactive than an alkaline-earth metal in the same period.

## Who decides a new element's name?

### What's the Issue?

When Mendeleev first published his periodic table, would he have been surprised to learn that scientists are still updating this ultimate source of chemical information 150 years later? Today, all of the elements that occur naturally have been discovered. Therefore, the discovery of new elements involves making them in laboratories and analyzing complex results to confirm their existence. Who decides when a new element has been made and what to call it?

The International Union of Pure and Applied Chemistry, or IUPAC for short, is the international scientific organization that is in charge of naming chemical elements, as well as other chemicals. They are also in charge of confirming that new elements have actually been synthesized. In 2016, IUPAC confirmed that the new elements numbered 113, 115, 117, and 118 actually existed, and assigned these elements temporary names that were added to the periodic table. The seventh row of the periodic table was completed when these four elements were assigned official names and symbols as shown below.

### Newly Synthesized Elements

Element Number	Name	Symbol
113	nihonium	Nh
115	moscovium	Mc
117	tennessine	Ts
118	oganesson	Og



### Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. According to IUPAC, what are the rules for naming new elements? What were the reasons behind the names for new elements 113, 115, 117, and 118? What were the temporary names given to these elements before their official names were decided?
2. IUPAC announced the four new names in June 2016. They then waited 5 months to allow for both scientific and non-scientific people to review the names. Why did IUPAC do this?
3. Choose a synthetic element and find out how it was made. How does IUPAC confirm the synthesis of a new element? Why are multiple results required to make this decision?
4. Does the naming of these last four elements mean that scientists are finished making new elements and that the periodic table is complete? Explain your answer.

## Check Your Understanding of Topic 2.3

QP Questioning and Predicting   PC Planning and Conducting   PA Processing and Analyzing   E Evaluating  
AI Applying and Innovating   C Communicating

### Understanding Key Ideas

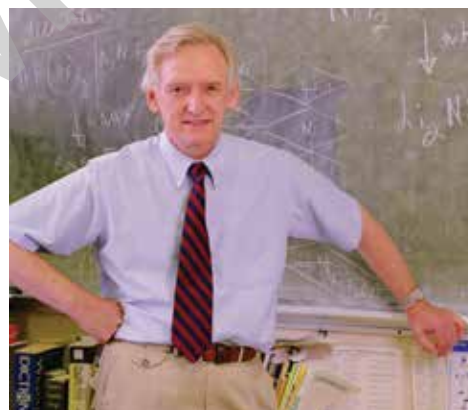
1. What is a periodic trend? **PA C**
2. Compare the number of protons and electrons in each of the following: **PA C**
  - a) a positively charged ion
  - b) a negatively charged ion
  - c) a neutral atom
3. Why are the noble gases so stable? **PA C**
4. What is the relationship between reactivity among elements (other than the noble gases) and the number of valence electrons? **PA**
5. Describe and explain the periodic trends relating to atomic sizes. **PA C**
6. Which of the following pairs of metals would you expect to be more reactive? Briefly explain your answers. **QP PA C**
  - a) potassium or calcium?
  - b) rubidium or potassium?
7. How many valence electrons do atoms in the following groups have? (If there are exceptions to the rule, state them.) **PA**
  - a) Group 1                      c) Group 17
  - b) Group 2                     d) Group 18

### Connecting Ideas

8. Do you expect a calcium ion,  $\text{Ca}^{2+}$ , to be larger or smaller than a calcium atom? Explain your answer. **QP PA C**
9. The noble gases were not identified until after Mendeleev first published his periodic table. Use your knowledge of noble gases to infer why it took so long to discover them. **E C**

### Making New Connections

10. Fluorine is the most reactive of the halogens. It is more reactive than chlorine, which is just below it. Bromine is less reactive than chlorine. How would you summarize and explain this trend? **PA AI C**
11. Neil Bartlett, shown below, was a chemist and a teacher at the University of British Columbia who specialized in the chemistry of the element fluorine. Bartlett is celebrated as the first chemist to succeed in getting a noble gas to react and form a compound. **PA E AI C**



- a) Bartlett was working on getting the noble gas xenon to react with fluorine. He eventually succeeded in making a number of compounds of xenon and fluorine. Why do you think fluorine was a good choice of element to work with in trying to get noble gases to react? **Hint:** Refer to Question 10.
- b) What features of xenon made it a good choice of noble gas for Bartlett to use in his attempts to get a noble gas to react? Research to find out.
- c) What effect did Bartlett's discovery have? Research to find out.



**Skills and Strategies**

- Planning and Conducting
- Processing and Analyzing
- Communicating

**Safety**

- Hydrochloric acid can burn skin.
- Clean up any spills and inform your teacher immediately.
- Do not handle calcium with your bare hands.

**What You Need**

- water
- 3 test tubes
- test-tube rack
- aluminum
- pea-sized piece of calcium
- 1 cm strip magnesium ribbon
- 1 mol/L hydrochloric acid

## Reactivity Trends in the Periodic Table

Periodic trends include both physical and chemical properties of elements. In this investigation, find out if (and how) the reactivity of metals relates to their position on the periodic table.

**Question**

Is there a relationship between the reactivity of a metal and its position in the periodic table?

**Procedure**

1. Read the Procedure steps and design a table to record your observations.
2. Put 10 mL of water into each of the three test tubes. Add one metal to each test tube. Record your observations.
3. When the reactions stop, dispose of the liquid as directed by your teacher. You will use the magnesium and aluminum metals again for the next step.
4. Add 10 mL of HCl to the remaining magnesium and aluminum samples. Record your observations and indicate the relative reactivity of each metal. CAUTION: Be very careful when working with the hydrochloric acid. Acid can burn skin. If you spill any of the acid solution on your hands, rinse it off immediately with cold water and inform your teacher.
5. Clean up your work area and dispose of materials as directed by your teacher.

### Analyze and Interpret

1. Compare the reactivities of magnesium and calcium. Use evidence to support your comparison.
2. Compare the reactivities of magnesium and aluminum. Use evidence to support your comparison.
3. Which of the three metals was the most reactive? Which metal was the least reactive?

### Conclude and Communicate

4. Draw Bohr diagrams for magnesium, calcium, and aluminum. Does your understanding of atomic structure support your observations from this investigation? Justify your response.

### Apply and Innovate

5. What other metals could you test in this way?
  - a) Suggest two or three additional metals that you could test.
  - b) Write a procedure for testing the reactivity of the metals. Include safety precautions.
  - c) With your teacher's permission, carry out your procedure.
  - d) Make a brief digital slide show to compare and analyze the findings of your own investigation together with your results from Investigation 2-E.
6. What other questions do you have about the different reactivities of elements as a result of carrying out this investigation?
  - a) Choose one question to investigate.
  - b) Conduct research to help you come up with a procedure for investigating your question in the laboratory.
  - c) Write a procedure for investigating your question.
  - d) With your teacher's permission, carry out your procedure.
  - e) Write a brief report to describe your investigation and your results.