1.1 Elements and the Periodic Table

element: a pure substance that cannot be broken down into simpler substances by chemical means (empirical definition); a substance composed entirely of only one kind of atom (theoretical definition)

compound: a pure substance that can be broken down by chemical means to produce two or more pure substances (empirical definition); a substance containing atoms of more than one element combined in fixed proportions (theoretical definition)

metal: an element that is a conductor of electricity, malleable, ductile, and lustrous

SATP (standard ambient temperature and pressure): exactly 25°C and 100 kPa

STP (standard temperature and pressure): exactly 0°C and 101.325 kPa

empirical definition: a statement that defines an object or process in terms of observable properties

Long before recorded history, humans used **elements** for many purposes. Copper, silver, and gold were put to many uses, both decorative and practical, in China and western Asia. At the dawn of recorded history, ancient peoples discovered that another element, tin, could be combined with copper to make a much harder material (bronze) from which they made stronger cutting tools, more effective weapons, and mirrors (**Figure 1**). About 2500 B.C., residents of what is now Turkey learned to extract iron from iron ore. The Egyptians used cobalt to make blue glass and antimony in cosmetics. In the first few centuries A.D., the Romans discovered how to use lead to make water pipes and eating utensils.

Many modern scientists study elements in great detail. As a result, we have developed thousands of new uses for elements and theories to explain their properties. We even have technologies that can create images of the atoms that make up elements. Elements are pure substances that cannot be broken down into simpler substances by chemical means. However, elements can be chemically combined to form more complex pure substances known as **compounds**.

The majority of the known elements are **metals**. All metals except mercury are solids at **SATP** (**standard ambient temperature and pressure**)**,** which is defined as exactly 25°C and 100 kPa. When you work with gases in Chapter 9, you will find that there is another set of standard conditions, **STP** (**standard temperature and pressure**), which is exactly 0°C and 101.325 kPa.

From many observations of the properties of elements, scientists have developed an **empirical definition** for metals: They are malleable, ductile, and conductors of electricity. Metals are also described as *lustrous*, or shiny. You may be very familiar with some metals (e.g., iron, copper, calcium) but less so with others (e.g., vanadium, rhodium, osmium).

Figure 1
Bronze was put to use by artists from the moment of its discovery. This piece was created by an artist in ancient China.

The remaining known elements are mostly nonmetals. **Nonmetals** are generally nonconductors of electricity in their solid form. At SATP, the nonmetals are mostly gases or solids (**Figure 2**). Solid nonmetals are brittle and lack the lustre of metals. Some of the more familiar nonmetals include oxygen, chlorine, sulfur, and neon.

Some elements clearly do not fit the empirical definition for either metals or nonmetals. These elements are members of a small class known as **metalloids**. These elements are found near the blue "staircase line" that divides metals from nonmetals on the periodic table (**Figure 3**). Boron, silicon, and antimony are all metalloids.

nonmetal: an element that is generally a nonconductor of electricity and is brittle

metalloid: an element located near the "staircase line" on the periodic table; having some metallic and some nonmetallic properties

IUPAC: the International Union of Pure and Applied Chemistry; the international body that approves chemical names, symbols, and units

Naming Elements

As there are over 100 known elements; memorizing all of their names is a formidable task. Communicating across language barriers can be even more daunting. This issue was addressed by Swedish chemist Jöns Jakob Berzelius (1779–1848) in the early 19th century. In 1814, he suggested using a code of letters as symbols for elements. In this system, which is still used today, the symbol for each element consists of either a single uppercase letter or an uppercase letter followed by a lowercase letter. Because Latin was a common language of communication in Berzelius's day, many of the symbols were derived from the Latin names for the elements (**Table 1**). Today, although the names of elements are different in different languages, the same symbols are used in all languages. Scientific communication throughout the world depends on this language of symbols, which is international, precise, logical, and simple. The International Union of Pure and Applied Chemistry (**IUPAC**) specifies rules for chemical names and symbols.

Table 1: Selected Symbols and Names of Elements

International symbol	Latin	English	French	German
Ag	argentum	silver	argent	Silber
Au	aurum	gold	or	Gold
Cu	cuprum	copper	cuivre	Kupfer
Fe	ferrum	iron	fer	Eisen
Hg	hydrargyrum	mercury	mercure	Quecksilber
K	kalium	potassium	potassium	Kalium
Na	natrium	sodium	sodium	Natrium
Pb	plumbum	lead	plomb	Blei
Sb	stibium	antimony	antimonie	Antimon
Sn	stannum	tin	étain	Zinn

These rules are summarized in many scientific references, such as the *Handbook of Chemistry and Physics*, and used all over the world.

For elements, the first letter (only) of the symbol is always an uppercase letter. For example, the symbol for calcium is Ca, *not* CA, ca, or cA. New elements are still being synthesized. There are rules for naming these new elements. The names of new metallic elements end in "ium." The new elements first get a temporary name, with symbols consisting of three letters. Later permanent names and symbols are given, by a vote of IUPAC representatives from each country. The permanent name might reflect the country in which the element was discovered, or pay tribute to a notable scientist.

Practice

Understanding Concepts

1. Referring to the periodic table, classify each of the following elements as metals, metalloids, or nonmetals.
   (a) iron
   (b) aluminum
   (c) gallium
   (d) carbon
   (e) silver
   (f) oxygen
   (g) silicon
2. (a) What does the acronym IUPAC represent?
   (b) In a paragraph, explain why this organization is necessary.
3. State three sources of names for elements.

Making Connections

4. Choose five household products. List the ingredients from their product labels. Classify the ingredients as either elements or compounds. Further classify each of the elements, including elements in compounds, as metal, metalloid, or nonmetal.
5. Aluminum is a metal that has two important technological advantages: It has a low density and is easily cast, for example, into cooking pots and components for engines. Use the Internet to research the possible link between aluminum and Alzheimer's disease. Do you consider aluminum to be a significant environmental hazard?

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DID YOU KNOW ?

Why Set a Standard?

SATP, standard ambient temperature and pressure, was established by international agreement of scientists to approximate normal conditions in the laboratory. For convenience and comparison, scientists need to communicate the value of a constant, such as density or solubility, under the same conditions as other scientists. Conditions such as these are called standard conditions. It is often easier to determine and more convenient to use values for SATP than for STP. It's not much fun working at 0°C, and the water keeps freezing!

Figure 2
Nonmetallic elements are rarely seen. The solids, such as these piles of sulfur, are generally used as raw materials to produce other substances.

12	13	14	15	16	17
	5 B	6 C	7 N	8 O	9 F
	13 Al	14 Si	15 P	16 S	17 Cl
30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br
48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I
80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At

Figure 3
The properties of some elements, which are like both metals and nonmetals, have led to the creation of the metalloids category of elements.

DID YOU KNOW ?

Properties of Gold

Gold is easily identified as a metal because of its properties. It is an excellent conductor of electricity and so ductile that it can be drawn into the very fine wires needed in tiny electronic devices. It is so malleable that it can be hammered into gold leaf, or rolled into layers only a few atoms thick. Using this property, it would be possible to roll 1 cm^3 of gold into a layer so thin and so flat that it could cover the roof of your school.

6. Choose two elements from the periodic table—one metal and one nonmetal. Research the discovery of these two elements. Include in your report how, when, where, and by whom they were discovered. What are some common industrial or technological applications of these elements?

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Reflecting

7. Why would it be unwise for each country to choose its own names and symbols for elements?
8. Classification is not restricted to science. To make the world easier to understand, we classify music, food, vehicles, and people. Give an example of a useful classification system that you have encountered in your life. In what way is it useful? Describe a harmful example. Why do you think it is harmful?

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Investigation 1.1.1

Element or Compound?

Before 1800, scientists distinguished elements from compounds by heating the substances to find out if they decomposed. If the products they obtained after cooling had different properties from the starting materials, then the experimenters concluded that decomposition had occurred, so the original substance was a compound, rather than an element. This experimental design was the only one known at that time.

In this investigation, you will test this experimental design by heating some samples and classifying the substances as either elements or compounds. Carry out the **Procedure** and complete the **Prediction**, **Analysis,** and **Evaluation** sections of the lab report.

You will use cobalt(II) chloride paper in a **diagnostic test** for water. If cobalt(II) chloride paper is exposed to a liquid or vapour, and the paper turns from blue to pink, then water is likely present. The presence of water above a solid sample may indicate that decomposition has taken place.

diagnostic test: an empirical test to detect the presence of a chemical

Question

Are water, bluestone, malachite, table salt, and sugar elements or compounds?

Prediction

(a) Referring to their chemical formulas, and using the definition for element and compound, predict the answer to the Question.

Experimental Design

A sample of each substance is heated, and any evidence of chemical decomposition is recorded. Decomposition is taken as evidence that the substance is a compound.

Materials

lab apron
distilled water, $H_2O_{(l)}$
malachite, $Cu(OH)_2 \cdot CuCO_{3(s)}$
sugar (sucrose), $C_{12}H_{22}O_{11(s)}$
250-mL Erlenmeyer flask
laboratory burner and striker
crucible
hot plate
utility clamp and stirring rod
piece of aluminum foil
eye protection
bluestone, $CuSO_4 \cdot 5H_2O_{(s)}$
table salt, $NaCl_{(s)}$
cobalt(II) chloride paper
laboratory scoop
ring stand and wire gauze
clay triangle
large (150-mL) test tube
medicine dropper

Wear eye protection and an apron.

Bluestone and malachite are harmful if swallowed.

Tie back hair and any articles of loose clothing.

Procedure

Part 1: Testing Water for Decomposition

1. Test some cobalt(II) chloride paper by placing a few drops of distilled water on the paper and noting any change in colour.
2. Pour distilled water into an Erlenmeyer flask until the water is about 1 cm deep. Set up the apparatus as shown in **Figure 4(a)**.
3. Dry the inside of the top of the Erlenmeyer flask. Place a piece of cobalt(II) chloride paper across the mouth of the flask.
4. Carefully boil the water. Record your observations.

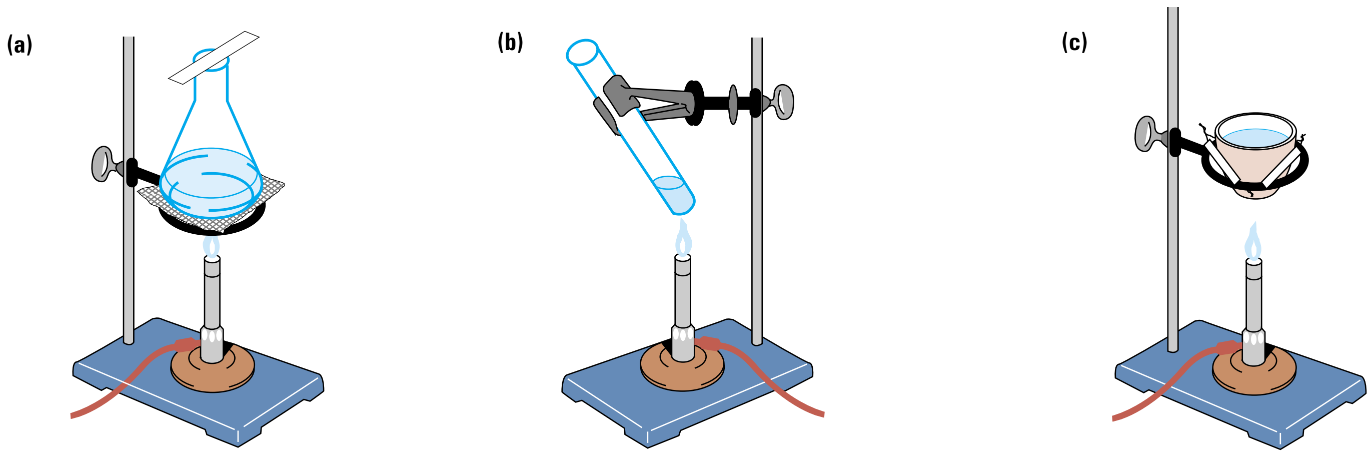


Figure 4
Methods of heating:
(a) An Erlenmeyer flask is used to funnel vapours.
(b) A test tube is used when heating small quantities of a chemical.
(c) A crucible is required when a substance must be heated strongly.

Part 2: Heating To Test for Decomposition

5. Place some bluestone to a depth of about 0.5 cm in a clean, dry test tube. Set up the apparatus as shown in **Figure 4(b)**.
6. Heat the sample carefully. Use cobalt(II) chloride paper to test for water vapour. Record your observations.
7. Set a crucible in the clay triangle on the iron ring as shown in **Figure 4(c)**. Add only enough malachite to cover the bottom of the crucible with a thin layer.
8. Heat the malachite sample slowly, with a uniform, almost invisible flame. Use cobalt(II) chloride paper to test for water vapour. Record your observations.
9. Heat the malachite sample strongly with a two-part flame. Use cobalt(II) chloride paper to test for water vapour. Record your observations.
10. Place a few grains of table salt and a few grains of sugar in two separate locations on a piece of aluminum foil. Place the foil on a hot plate.
11. Set the hot plate to maximum heat and record your observations.
12. Dispose of waste materials as instructed by your teacher.

Analysis

(b) Which substances decomposed upon heating? How do your observations support your answer?

(c) Which substances did not decompose upon heating? How do your observations support your answer?

(d) According to your observations, and the concept that heating will decompose compounds, answer the Question: Are water, bluestone, malachite, table salt, and sugar elements or compounds?

Evaluation

(e) Compare the answer you obtained in your Analysis to your Prediction. Assuming your Prediction is valid, what does this suggest about the Experimental Design?

(f) What are some limitations of using heating to determine whether a substance is an element or a compound?

Synthesis

(g) Why might you draw different conclusions from your Evidence than earlier experimenters did from their similar results?

(h) Write an alternative Experimental Design to better answer the Question.

Organizing the Elements

In 1800, 31 elements were known. By 1865, the number of identified elements had more than doubled to 63. With the discovery of more and more elements, scientists searched for a systematic way to organize their knowledge by classifying the elements. Scientists were able to make more accurate and precise measurements of mass, volume, and pressure in the course of their investigations. By studying the reactions of various elements with oxygen and using the quantitative relationships that emerged, scientists eventually determined the relative atomic mass of each element. For example, atoms of carbon were found to have a mass 12 times the mass of a hydrogen atom; and an oxygen atom has a mass 16 times that of a hydrogen atom. Atoms of hydrogen appeared to be the lightest, so

DID YOU KNOW ?

Solid, Liquid, or Gas?

When representing an element or compound by its chemical formula, we can indicate its state with a subscript: (s) means solid; (l) means liquid; (aq) means "aqueous," dissolved in water; and (g) means gaseous. All of these states are at SATP—25°C and 100kPa—unless stated otherwise.

a scale was devised in which hydrogen had an atomic mass of 1 unit. The relative atomic masses of some common elements are shown in **Table 2**.

Johann Döbereiner (1780–1849) was among the first scientists to consider the idea of trends among the properties of the elements. By 1829 he had noted a similarity among the physical and chemical properties of several groups of three elements. In each case, the middle element had an atomic mass about halfway between the atomic masses of the other two. Lithium, potassium, and sodium make up one such **triad**.

Döbereiner's discovery is often referred to as the law of triads. However, for a statement to be accepted as a law, evidence must first be collected from several examples and replicated by many scientists. Laws must accurately describe and explain current observations and predict future events in a simple manner. A law is a statement of accepted knowledge. In this regard, Döbereiner's "law of triads" was never really a law. In any event, at the time, Döbereiner's idea was dismissed as coincidence.

In 1864, the English chemist John Alexander Newlands (1837–1898) arranged all of the known elements in order of increasing atomic mass. He noticed that similar physical and chemical properties appeared for every eighth element. For example, the elements lithium, sodium, and potassium are all soft, silvery-white metals. They are all highly reactive, and they form similar compounds with chlorine. There is a strong "family" resemblance among them, although the degree of reactivity increases as the atomic mass increases within the family. Newlands noticed that rubidium and cesium, although they did not follow the "eighth element" pattern, share properties with sodium, potassium, and lithium. He therefore decided to include them in the same family.

The elements that follow (in atomic mass) each of these five in Newlands's arrangement—beryllium, magnesium, calcium, strontium, and barium—also exhibit a strong family resemblance. Newlands, having an interest in opera and music, drew a parallel between the repeating properties of every eighth chemical element and the octave scale in music. Newlands called his discovery "the law of octaves." However, Newlands's law of octaves seemed to be true only for elements up to calcium. As a result, the idea was not generally accepted and drew criticism and even ridicule from members of the scientific community.

At around the same time that Newlands announced his findings, a German chemist, Julius Lothar Meyer (1830–1895), also arranged the elements in order of atomic mass. Lothar Meyer thought he found a repeating pattern in the relative volumes of the individual atoms of known elements. Unlike Newlands, Lothar Meyer observed a change in length of that repeating pattern. By 1868, Lothar Meyer had developed a table of the elements that closely resembles the modern periodic table. However, his work was not published until after the work of Dmitri Mendeleev (1834–1907), the scientist who is generally credited with the development of the modern periodic table.

Mendeleev's Periodic Table

While Döbereiner may have initiated the study of periodic (repeating) relationships among the elements, it was the Russian chemist Dmitri Mendeleev who was responsible for publishing the first **periodic law**. Mendeleev's periodic law stated that elements arranged in order of increasing atomic mass show a periodic recurrence of properties at regular intervals.

In 1869, Mendeleev (**Figure 5**) reported observing repeated patterns in the properties of elements, similar to the interpretations of Newlands and Meyer. Mendeleev first created a table listing the elements in order of atomic mass in

Table 2: Relative Atomic Masses of Selected Elements

Element	Relative atomic mass
hydrogen	1
carbon	12
oxygen	16
sodium	23
sulfur	32
chlorine	35.5
copper	63.5
silver	108
lead	207

triad: a group of three elements with similar properties

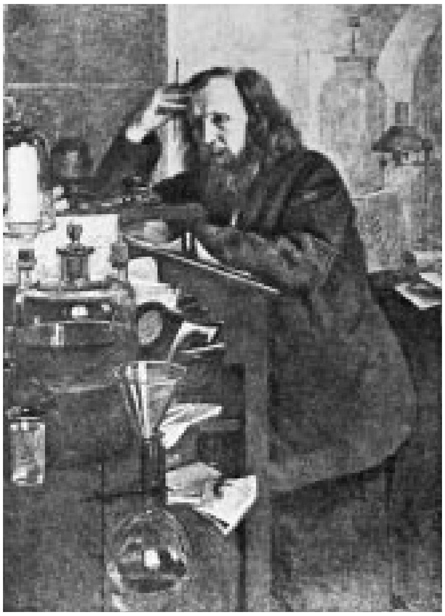


Figure 5
Dmitri Mendeleev (1834–1907) was born in Siberia, the youngest of 17 children. Whilst employed as a chemistry professor, he explored a wide range of interests including fossil fuels, meteorology, and hot-air balloons.

periodic law (according to Mendeleev): The properties of the elements are a periodic (regularly repeating) function of their atomic masses.

GROUP		I	II	III	IV	V	VI	VII	VIII
Formula of Compounds		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)	
	8	Cs (133)	Ba (137)	?Di (138)	?Ce (140)	—	—	—	
	9	—	—	—	—	—	—	—	
	10	—	—	?Er (178)	?La (180)	Ta (182)	W (184)	—	Os (195), Ir (197) Pt (198), Au (199)
	11	[Au (199)]	Hg (200)	Tl (204)	Pb (207)	Bi (208)	—	—	
	12	—	—	—	Th (231)	—	U (240)		

Figure 6
Mendeleev's revised periodic table of 1872. Later, scientists rearranged the purple boxes to form the middle section of the modern periodic table. (For the formulas shown, "R" is used as the symbol for any element in that family.) Note that some of the symbols of the elements have changed since 1872, and modern values of atomic mass may differ.

vertical columns. Each column ended when the chemical properties of the elements started to repeat themselves, at which point a new column was started.

Mendeleev later published a revised periodic table of the elements. In this table he listed all the elements known at that time in horizontal rows, in order of atomic mass. The table is organized in such a way that elements with similar properties appear in the same column or group (**Figure 6**). This table made it very clear that there were **trends** (sometimes called **periodic trends**) among the elements: similar but gradually changing properties, such as melting and boiling points.

trend or **periodic trend:** a gradual and consistent change in properties within periods or groups of the periodic table

Mendeleev's table contained some blank spaces where no known elements appeared to fit. However, he had such confidence in his hypothesis that he proposed that those elements had not yet been discovered. For example, in the periodic table there is a gap between silicon, Si (28), and tin, Sn (118). Mendeleev predicted that an element, which he called "eka-silicon" (after silicon), would eventually be discovered and that this element would have properties related to those of silicon and tin. He made detailed predictions of the properties of this new element, using his knowledge of periodic trends. Sixteen years later, a new element was discovered in Germany. The properties of this new element, germanium, are listed in **Table 3**, beside the properties that Mendeleev had predicted for eka-silicon. The boldness of Mendeleev's quantitative predictions and their eventual success made him and his periodic table famous.

Table 3: Germanium Fulfills Mendeleev's Prediction

Property	Predicted for eka-silicon (1871)	Observed for germanium (1887)
atomic mass	72 (average of Si and Sn)	72.5
specific gravity	5.5 (average of Si and Sn)	5.35
reaction with water	none (based on none for Si and Sn)	none
reaction with acids	slight (based on Si—none; Sn—rapid)	none
oxide formula	XO_2 (based on SiO_2 and SnO_2)	GeO_2
oxide specific gravity	4.6 (average of SiO_2 and SnO_2)	4.1
chloride formula	XCl_4 (based on $SiCl_4$ and $SnCl_4$)	$GeCl_4$
chloride boiling point	86°C (average of $SiCl_4$ and $SnCl_4$)	83°C

No one in the scientific community at the time could explain *why* Mendeleev's predictions were correct—no acceptable theory of periodicity was proposed until the early 1900s. Mendeleev was working on empirical evidence alone. This mystery must have made the accuracy of his predictions even more astounding.

Practice

Understanding Concepts

9. (a) State the periodic law according to Mendeleev.
   (b) What are the limitations of the periodic law? Do you think it could be used to predict all of the properties of a new element?
10. Chlorine, fluorine, and bromine are a "triad" with increasing atomic mass. The atomic mass of fluorine is 19 and of bromine is 80. According to the law of triads, predict the atomic mass of chlorine. Compare your prediction to the accepted value in the periodic table.
11. Name three scientists who contributed to the development of the periodic table, and briefly describe the contributions of each.
12. Sulfur is a yellow solid and oxygen is a colourless gas, yet both elements are placed in the same column or family. What properties might have led Mendeleev to place them in the same family?
13. In the 1890s, an entirely new family of elements was discovered. This family consisted of unreactive gases called noble gases. Did this discovery support Mendeleev's periodic table? Explain briefly.

Reflecting

14. Science is considered by many people to be completely objective. However, the history of science shows that this is not always the case. Research the historical contributions of 19th-century scientists, such as Newlands and Lothar Meyer, to the development of the modern periodic law. Using your findings as evidence, write a brief commentary on the objectivity of science and its social and personal dimensions.

The Modern Periodic Table

Mendeleev developed his periodic table when chemists knew nothing about the internal structure of atoms. However, the beginning of the 20th century witnessed profound developments in theories about subatomic particles. In 1911, a Dutch physicist, A. van den Broek (1856–1917), suggested a rearrangement of the periodic table according to atomic number. This led to a revision of the **periodic law**. **Figure 7** shows the modern periodic table. In this table every element is in

periodic law: (modern definition) When the elements are arranged in order of increasing atomic number, their properties show a periodic recurrence and gradual change.

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															21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr															39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	72 Hf	73 Ta	74 W	75 Re	75 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Uun	111 Uuu	112 Uub	113	114 Uuq	115	116 Uuh	117	118 Uuo

Figure 7
Because of its inconvenient shape, this extended form of the periodic table is rarely used.

sequence, but the shape of the table makes it difficult to print on a page while still including useful descriptions of each element.

The periodic table is usually printed in the form shown in **Figure 8**, with two separate rows at the bottom. Note the following important features:

group: a column of elements in the periodic table; sometimes referred to as a family

period: a row in the periodic table

- a **group**—elements with similar chemical properties in a vertical column in the main part of the table;
- a **period**—elements, arranged in a horizontal row, whose properties change from metallic on the left to nonmetallic on the right;
- the "staircase line"—a zigzag line that separates metals (to the left) from nonmetals (to the right);
- the physical state of each element at SATP (in this case red for gases, blue for liquids; the remainder are solids);
- group numbers 1 to 18.

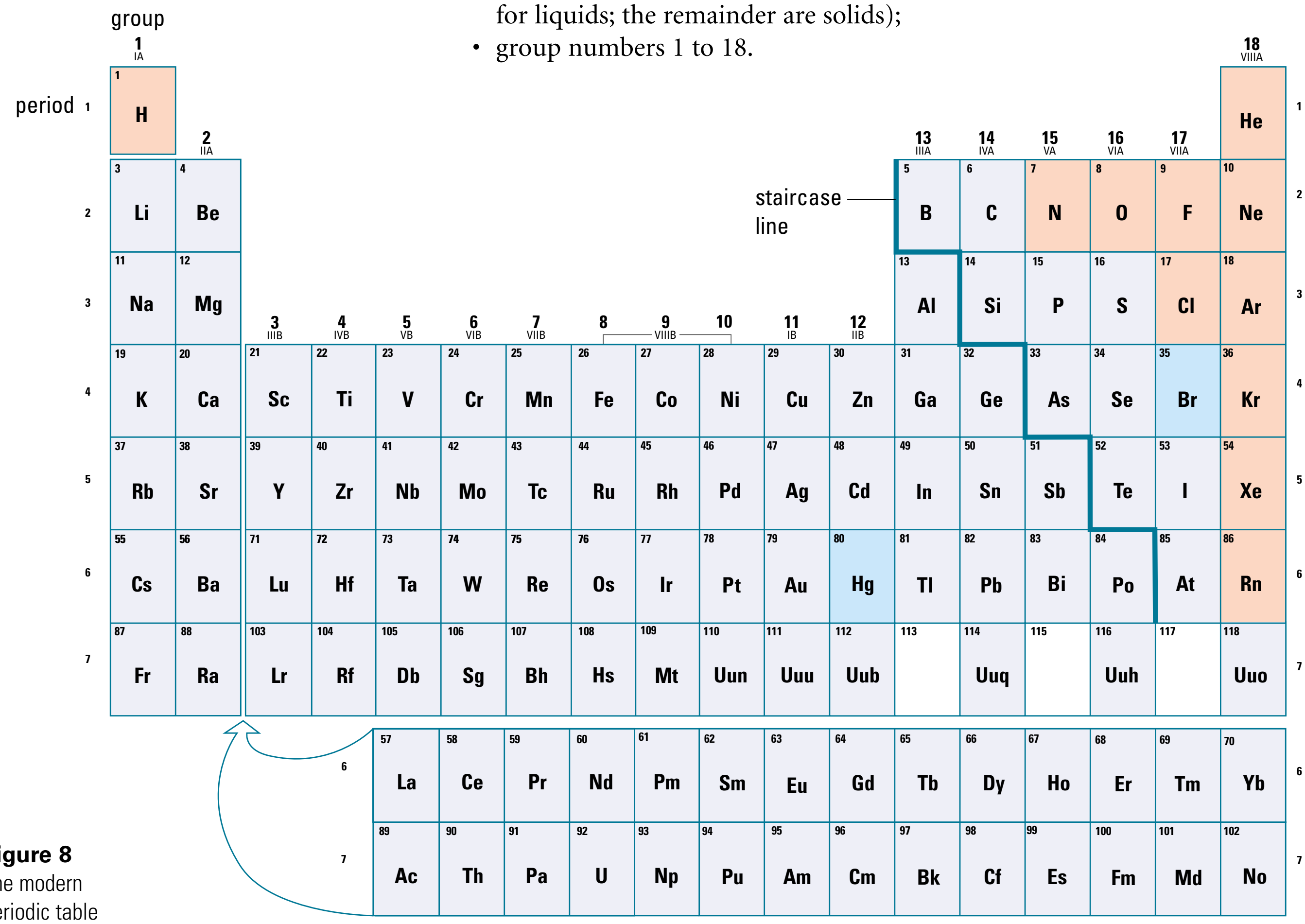


Figure 8
The modern periodic table

DID YOU KNOW ?

Not Completely Inert

Although the noble gases are so stable and unreactive that they remained undiscovered until the late 1800s, they can be made, under certain circumstances, to form compounds. The first known reaction involving a noble gas was a Canadian achievement. In 1962 Neil Bartlett (b. 1932), a scientist at the University of British Columbia, created a compound from xenon, platinum, and fluorine.

Names of Groups and Series of Elements

Some groups of elements and the two series of elements (those in the two horizontal rows at the bottom of the periodic table) have traditional names that are commonly used in scientific communication (**Figure 9**).

The position of hydrogen in the periodic table is a problem: It sometimes behaves like a member of the alkali metals, sometimes like halogens, and sometimes in its own unique way. Hydrogen is sufficiently different to be in a class by itself.

Although the periodic table has some limitations, scientists generally agree that the evidence supporting its general principles, as well as its usefulness in chemistry, make it an essential part of the study of chemistry.

alkali metals
soft, silver-coloured elements; solids at SATP; exhibit metallic properties; react violently with water to form basic solutions and liberate hydrogen gas; react with halogens to form compounds similar to sodium chloride, $NaCl_{(s)}$; stored under oil or in a vacuum to prevent reaction with air

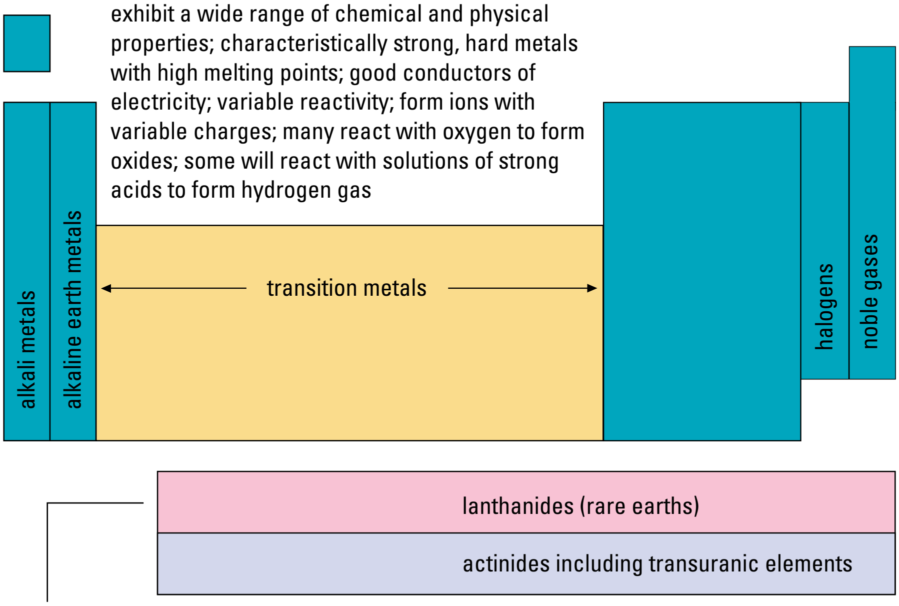
alkaline earth metals
light, very reactive metals; solids at SATP; exhibit metallic properties; form oxide coatings when exposed to air; react with oxygen to form oxides with the general chemical formula, $MO_{(s)}$; all except beryllium will react with hydrogen to form hydrides with the general chemical formula XH_2; react with water to liberate hydrogen

noble gases
gases at SATP; low melting and boiling points; extremely unreactive, making them especially interesting to chemists; krypton, xenon, and radon reluctantly form compounds with fluorine; radon is radioactive

halogens
may be solids, liquid, or gases at SATP; exhibit nonmetallic properties—not lustrous and nonconductors of electricity; extremely reactive, with fluorine being the most reactive; react readily with hydrogen and metals

representative elements
includes both metals and nonmetals from Groups 1, 2, and 13 through 17; may be solids, liquids, or gases at SATP; called representative because they most closely follow the periodic law; many form colourful compounds

transition metals
exhibit a wide range of chemical and physical properties; characteristically strong, hard metals with high melting points; good conductors of electricity; variable reactivity; form ions with variable charges; many react with oxygen to form oxides; some will react with solutions of strong acids to form hydrogen gas



lanthanides
(rare earth elements) elements with atomic numbers 57 to 70

actinides
elements with atomic numbers 89 to 102

transuranic elements
synthetic (not naturally occurring) elements with atomic numbers 93 or greater (beyond uranium)

Figure 9
The various parts of the periodic table are given specific names.

alkali metal: an element in Group 1 of the periodic table

alkaline earth metal: an element in Group 2 of the periodic table

noble gas: a element in Group 18 of the periodic table

halogen: an element in Group 17 of the periodic table

representative element: an element in any of Groups 1, 2, and 13 through 18

transition metal: an element in Groups 3 through 12 of the periodic table

lanthanide: lanthanum and the 13 elements that follow it in the 6th row of the periodic table; elements 57 to 70

actinide: actinium and the 13 elements that follow it in the 7th row of the periodic table; elements 89 to 102

transuranic elements: elements that follow uranium in the periodic table; elements 93+

Practice

Understanding Concepts

15. Create a table with five columns. At the top of the columns write the following headings: Element name; Atomic symbol; Atomic number; Group number; and State at SATP. In the left-hand column, write the names of all the elements in the second period, then complete the table.

DID YOU KNOW ?

Another Word for ...

Alkali is another word for base. Alkali metals were so named because they react with water to produce a basic solution.

16. Compare the numbers of metals, nonmetals, and metalloids in the periodic table.
17. The representative elements include elements from eight groups in the periodic table. Pick an element from each of the eight groups and list its properties.
18. List two physical and two chemical properties of the
    (a) alkali metals
    (b) halogens
    (c) noble gases
19. Nitrogen and hydrogen form the well-known compound $NH_{3(g)}$, ammonia, which is used in vast quantities to make chemical fertilizer. According to the position of phosphorus in the periodic table, predict the most likely chemical formula for a compound of phosphorus and hydrogen that is also in demand in the chemical industry.

Making Connections

20. Research and report upon the properties of silicon and its use in communications technology. Use your findings to write a paragraph commenting on the validity of the statement: Future historians will define the times we live in as the Age of Silicon.

    Follow the links for Nelson Chemistry 11, 1.1.

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Section 1.1 Questions

Understanding Concepts

1. Use examples of elements from the periodic table to show the effect of the periodic law.
2. The elements Li, Na, and K are arranged in descending order in a vertical column of the periodic table. Their melting points are 181°C, 97.8°C, and 63.3°C, respectively.
    (a) Using the periodic law, rather than reading the table, predict the melting point of Rb, the element immediately below K in the group.
    (b) Based on their melting points, would you classify these elements as metals or nonmetals? Give reasons.
    (c) What other physical properties would you expect these elements to share?
3. An unknown element, X, is a shiny, grey solid at SATP. When it is strongly heated in the presence of oxygen, a white, powdery solid forms on its surface.
    (a) Describe two ways in which the substance can be classified. Justify each classification.
    (b) If heated to high temperatures, the white powder is stable—it can be used to make firebrick and furnace linings. If heating of the grey solid and of the white powder had been observed by a scientist prior to 1800, what would the scientist have concluded about which was a compound and which was an element? Defend your answer.

4. Canada is rich in mineral deposits containing a variety of elements. **Table 4** lists a few examples from across Canada. In your notebook, copy and complete the table.

Table 4: Elements and Mineral Resources

Mineral resource or use	Element name	Atomic number	Element symbol	Group number	Period number	SATP state
(a) high-quality ores at Great Bear Lake, NT	radium					
(b) rich ore deposits at Bernic Lake, MB				1	6	
(c) potash deposits in Saskatchewan		19				
(d) large deposits in New Brunswick	antimony					
(e) extracted from Alberta sour natural gas			S			
(f) radiation source for cancer treatment				9	4	
(g) large ore deposits in Nova Scotia	barium					
(h) world-scale production in Sudbury, ON		28				
(i) fuel in CANDU nuclear reactors from Saskatchewan			U			
(j) fluorspar deposits in Newfoundland				17	2	
(k) large smelter in Trail, BC		30				

Applying Inquiry Skills

5. When an unknown element is added to water, it reacts violently to liberate hydrogen gas. Based on this reaction, to what groups might the element belong? What additional property could you investigate to narrow your choice of groups? Outline a possible Experimental Design.

(continued)

Making Connections

6. Select one of the elements listed in **Table 4**.
   (a) Where does it come from, how is it extracted, and what is it used for?
   (b) Does it pose any health or environmental hazards? How should it be handled?
   (c) Do the advantages of having this element available outweigh the drawbacks? To help you decide, separate your findings into two categories: advantages and drawbacks. Write a paragraph summarizing your findings and explaining your position.

   Follow the links for Nelson Chemistry 11, 1.1.

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1.2 Developing a Model of the Atom

empirical knowledge: knowledge coming directly from observations

theoretical knowledge: knowledge based on ideas created to explain observations

model: a mental or physical representation of a theoretical concept

analogy: a comparison of a situation, object, or event with more familiar ideas, objects, or events

theory: a comprehensive set of ideas that explains a law or a large number of related observations

In all aspects of our lives, we can achieve understanding through observations (experience). The same is true in science: Understanding comes from observing the natural world and trying to make sense of those observations. All scientific knowledge can be classified as either empirical (observable) or theoretical (non-observable). Generally, **empirical knowledge** comes first, and can be as simple as a description or as complex as a powerful scientific law. For example, the physical and chemical properties of some elements were known empirically for thousands of years before we had a theory to explain these properties. This is a common occurrence: Empirical knowledge is usually well developed before any explanation is generally accepted within the scientific community. Although scientific laws are important statements summarizing considerable empirical knowledge, they contain no explanation. For an explanation—an answer to the question "Why?"—a theory is required.

So far in this chapter, you have encountered only empirical knowledge of elements, based on what has been observed. But why do the properties of elements vary across the periodic table? Why are groups of elements similar in their physical and chemical properties? Can we explain the chemical formulas of compounds formed from elements? An answer to these and other questions about elements requires a theory about what makes up elements.

Curiosity leads scientists to try to explain nature in terms of what cannot be observed. This step—formulating ideas to explain observations—is the essence of **theoretical knowledge** in science. Albert Einstein referred to theoretical knowledge as "free creations of the human mind."

It is more challenging to communicate theoretical knowledge than empirical knowledge because ideas are, by definition, abstract and cannot be seen. Theoretical knowledge can be communicated in a variety of ways such as words, symbols, **models**, and **analogies**. The difference between an analogy and a model is not always obvious. Models are representations (**Figure 1**). Analogies are comparisons. For example, some properties of a liquid can be explained using the analogy of a crowd of people in a confined space.

Figure 1
A physical model to represent the motion of particles described by the kinetic molecular theory of gases could be a vibrating box containing marbles. In what ways is this model useful in describing air in a sealed container? In what ways is it deficient?

Theories are dynamic; they continually undergo refinement and change. To be acceptable to the scientific community, theories must

- *describe* observations in terms of non-observable ideas;
- *explain* observations by means of ideas or models;
- successfully *predict* results of future experiments; and
- be as *simple* as possible in concept and application.