

## Chapter 7

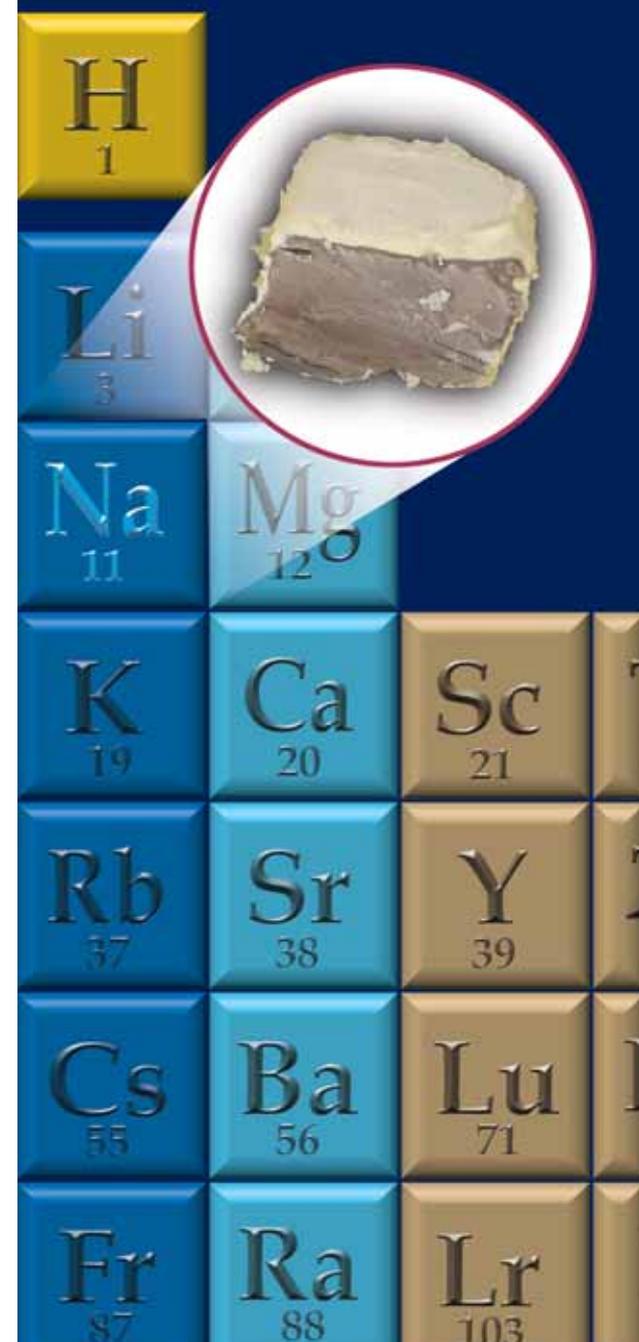
# Elements and the Periodic Table

What are metals like? Think of things that are made with metals like aluminum, copper, iron, and gold. What do they have in common? They are usually shiny, and they can often be bent into different shapes without breaking. Did you know there is a metal that is shiny, but is so soft it can be cut with a knife? This metal is very reactive. If you place a piece of this metal in water, it will race around the surface, and the heat given off is often enough to melt the metal and ignite the hydrogen gas that is produced! This strange metal is called sodium. You can look at the periodic table of elements to find other metals that behave like sodium. In this chapter, you will become familiar with how you can predict the properties of different elements by their location on the periodic table.



### Key Questions

1. *Why are the elements arranged in the periodic table?*
2. *What sort of information can the periodic table of elements give you?*
3. *Why does the periodic table have the shape that it does?*



## 7.1 The Periodic Table of the Elements

Before scientists understood how atoms were put together they were able to identify elements by their chemical properties. In this section, you learn how the elements are organized in the *periodic table*, and how an element's chemical properties are related to the arrangement of electrons.

### Physical and chemical properties

**Physical properties** Characteristics that you can see through direct observation are called **physical properties**. For example, water is a colorless, odorless substance that exists as a liquid at room temperature. Gold is shiny, exists as a solid at room temperature, and can be hammered into very thin sheets. Physical properties include color, texture, density, brittleness, and state (solid, liquid, or gas). Melting point, boiling point, and specific heat are also physical properties.

**Physical changes are reversible** Physical changes, such as melting, boiling, or bending are sometimes *reversible*, and no new substances are formed. When water freezes, it undergoes a physical change from a liquid to a solid. This does not change the water into a new substance. It is still water, only in solid form. The change can easily be reversed by melting the water. Bending a steel bar is another physical change.

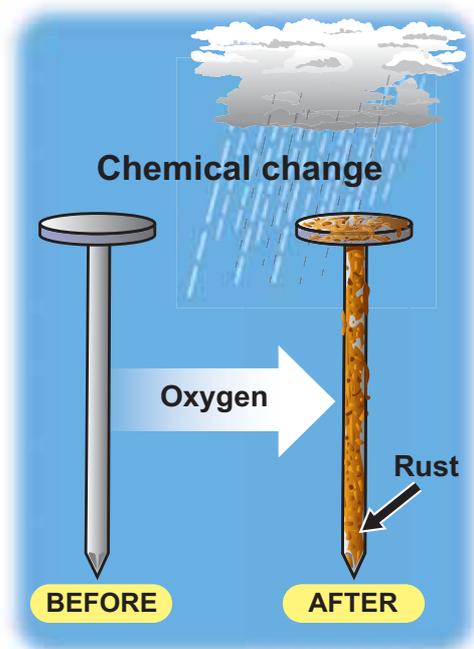
**Chemical properties** Properties that can only be observed when one substance changes into a different substance are called **chemical properties**. For example, if you leave an iron nail outside, it will eventually rust (Figure 7.1). A chemical property of iron is that it reacts with oxygen in the air to form iron oxide (rust).

**Chemical changes are hard to reverse** Any change that transforms one substance into a different substance is called a *chemical change*. The transformation of iron into rust is a chemical change. Chemical changes are not easily reversible. Rusted iron will not turn shiny again even if you take it away from oxygen in the air.

### VOCABULARY

**physical properties** - characteristics of matter that can be seen through direct observation such as density, melting point, and boiling point.

**chemical properties** - characteristics of matter that can only be observed when one substance changes into a different substance, such as iron into rust.



**Figure 7.1:** Rusting is an example of a chemical change.



## The periodic table

### How many elements are there?

In the 18th through 20th centuries, scientists tried to find and catalog all the elements that make up our universe. To do so, they had to carefully observe substances in order to identify them, and then try to break them apart by any possible means. If a substance could be chemically broken apart it could not be an element. As of this writing, scientists have identified 113 different elements, and five more are expected to be confirmed in the near future. Only 88 elements occur naturally. The others are made in laboratories.

### The modern periodic table

As chemists worked on determining which substances were elements, they noticed that some elements acted like other elements. The soft metals lithium, sodium, and potassium always combine with oxygen in a ratio of two atoms of metal per atom of oxygen (Figure 7.2). By keeping track of how each element combined with other elements, scientists began to recognize repeating patterns. From this data, they developed the first *periodic table of the elements*. The **periodic table** organizes the elements according to how they combine with other elements (chemical properties).

### Organization of the periodic table

Li	Element symbol
3	Atomic number
Lithium	Element name

The periodic table is organized in order of increasing atomic number. The lightest element (hydrogen) is at the upper left. The heaviest (#118) is on the lower right. Each element corresponds to one box in the periodic table identified with the element symbol.

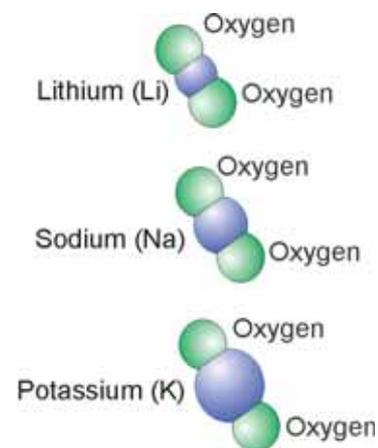
The periodic table is further divided into *periods* and *groups*. Each horizontal row is called a **period**. Across any period, the properties of the elements gradually change. Each vertical column is called a **group**. Groups of elements have similar properties. The *main group elements* are Groups 1-2 and 13-18 (the tall columns of the periodic table) Elements in Groups 3 through 12 are called the *transition elements*. The inner transition elements, called lanthanides and actinides, are usually put below to fit on a page.

### VOCABULARY

**periodic table** - a chart that organizes the elements by their chemical properties and increasing atomic number.

**period** - a row of the periodic table is called a period.

**group** - a column of the periodic table is called a group.



**Figure 7.2:** The metals lithium, sodium, and potassium all form compounds with two atoms of oxygen. All the elements in group one of the periodic table form compounds with two oxygen atoms.

## Reading the periodic table

### Metals, nonmetals, and metalloids

Most of the elements are metals. A **metal** is typically shiny, opaque, and a good conductor of heat and electricity as a pure element. Metals are also ductile, which means they can be bent into different shapes without breaking. With the exception of hydrogen, the nonmetals are on the right side of the periodic table. **Nonmetals** are poor conductors of heat and electricity. Solid nonmetals are brittle and appear dull. The elements on the border between metals and nonmetals are called *Metalloids*. Silicon is an example of a metalloid element with properties in between those of metals and nonmetals.

### VOCABULARY

**metal** - elements that are typically shiny and good conductors of heat and electricity.

**nonmetal** - elements that are poor conductors of heat and electricity.

**Periodic Table of the Elements**

  Main Group Elements  
   Non metals  
   Metalloids  
  Transition Elements  
   Metals

ROWS = PERIODS   COLUMNS = GROUPS

1	H 1 hydrogen	2											13	14	15	16	17	18
	Li 3 lithium	Be 4 beryllium											B 5 boron	C 6 carbon	N 7 nitrogen	O 8 oxygen	F 9 fluorine	Ne 10 neon
	Na 11 sodium	Mg 12 magnesium											Al 13 aluminum	Si 14 silicon	P 15 phosphorus	S 16 sulfur	Cl 17 chlorine	Ar 18 argon
	K 19 potassium	Ca 20 calcium	Sc 21 scandium	Ti 22 titanium	V 23 vanadium	Cr 24 chromium	Mn 25 manganese	Fe 26 iron	Co 27 cobalt	Ni 28 nickel	Cu 29 copper	Zn 30 zinc	Ga 31 gallium	Ge 32 germanium	As 33 arsenic	Se 34 selenium	Br 35 bromine	Kr 36 krypton
	Rb 37 rubidium	Sr 38 strontium	Y 39 yttrium	Zr 40 zirconium	Nb 41 niobium	Mo 42 molybdenum	Tc 43 technetium	Ru 44 ruthenium	Rh 45 rhodium	Pd 46 palladium	Ag 47 silver	Cd 48 cadmium	In 49 indium	Sn 50 tin	Sb 51 antimony	Te 52 tellurium	I 53 iodine	Xe 54 xenon
	Cs 55 cesium	Ba 56 barium											Tl 81 thallium	Pb 82 lead	Bi 83 bismuth	Po 84 polonium	At 85 astatine	Rn 86 radon
	Fr 87 francium	Ra 88 radium	Rf 104 rutherfordium	Db 105 dubnium	Sg 106 seaborgium	Bh 107 bohrium	Hs 108 hassium	Mt 109 meitnerium	Uun 110 ununilium	Uuu 111 unununium	Uub 112 ununbium	113	Uuq 114 ununquadium	115	116	117	118	
			La 57 lanthanum	Ce 58 cerium	Pr 59 praseodymium	Nd 60 neodymium	Pm 61 promethium	Sm 62 samarium	Eu 63 europium	Gd 64 gadolinium	Tb 65 terbium	Dy 66 dysprosium	Ho 67 holmium	Er 68 erbium	Tm 69 thulium	Yb 70 ytterbium	Lu 71 lutetium	
			Ac 89 actinium	Th 90 thorium	Pa 91 protactinium	U 92 uranium	Np 93 neptunium	Pu 94 plutonium	Am 95 americium	Cm 96 curium	Bk 97 berkelium	Cf 98 californium	Es 99 einsteinium	Fm 100 fermium	Md 101 mendelevium	No 102 nobelium	Lr 103 lawrencium	



## Atomic mass

**Atomic mass units** The mass of individual atoms is so small that the numbers are difficult to work with. To make calculations easier scientists define the **atomic mass unit (amu)**. One atomic mass unit is about the mass of a single proton (or a neutron). In laboratory units, one amu is  $1.66 \times 10^{-24}$  grams. That is 0.00000000000000000000000166 grams!

**Atomic mass and isotopes** The **atomic mass** is the *average* mass (in amu) of an atom of each element (chart below). Atomic masses differ from mass numbers because most elements in nature contain more than one isotope (see chart below). For example, the atomic mass of lithium is 6.94 amu. That does NOT mean there are 3 protons and 3.94 neutrons in a lithium atom! On average, out of every 100 g of lithium, 94 grams are Li-7 and 6 grams are Li-6 (Figure 7.3). The *average* atomic mass of lithium is 6.94 because of the mixture of isotopes.

### VOCABULARY

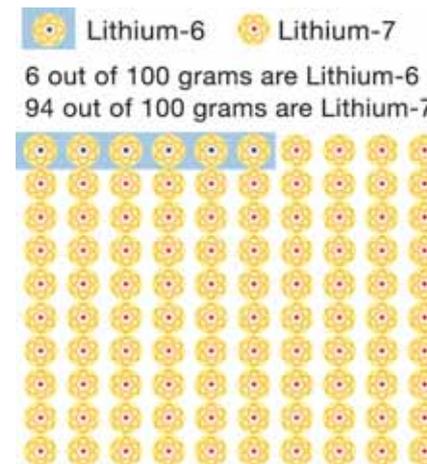
**atomic mass unit (amu)** - a unit of mass equal to  $1.66 \times 10^{-24}$  grams, which is one twelfth the mass of the isotope carbon-12.

**atomic mass** - the average mass of all the known isotopes of an element, expressed in amu.

1.008 1, 2 <b>H</b> 1							4.003 3, 4 <b>He</b> 2
6.941 6, 7 <b>Li</b> 3	9.012 9 <b>Be</b> 4	10.811 10, 11 <b>B</b> 5	12.011 12, 13 <b>C</b> 6	14.007 14, 15 <b>N</b> 7	15.999 16, 17, 18 <b>O</b> 8	18.998 19 <b>F</b> 9	20.180 20, 21, 22 <b>Ne</b> 10
22.990 23 <b>Na</b> 11	24.305 24, 25, 26 <b>Mg</b> 12	26.982 27 <b>Al</b> 13	28.086 28, 29, 30 <b>Si</b> 14	30.974 31 <b>P</b> 15	32.065 32, 33, 34, 36 <b>S</b> 16	35.453 35, 37 <b>Cl</b> 17	39.948 36, 38, 40 <b>Ar</b> 18

6.941	← Average atomic mass (amu)
6, 7	← Stable mass numbers
<b>Li</b>	← Element symbol
3	← Atomic number



**Figure 7.3:** Naturally occurring elements have a mixture of isotopes.

## Groups of the periodic table

### Alkali metals

Li 3
Na 11
K 19

The different groups of the periodic table have similar chemical properties. For example the first group is known as the **alkali metals**. This group includes the elements lithium (Li), sodium (Na), and potassium (K). The alkali metals are soft and silvery in their pure form and are highly reactive. Each of them combines in ratio of two to one with oxygen. For example lithium oxide has two atoms of lithium per atom of oxygen.

### Group 2 metals

Be 4
Mg 12
Ca 20

The group two metals include beryllium (Be), magnesium (Mg), and calcium (Ca). These metals also form oxides however they combine one-to-one with oxygen. For example, beryllium oxide has one beryllium atom per oxygen atom.

### Halogens

F 9
Cl 17
Br 35

The **halogens** are on the opposite side of the periodic table. These elements tend to be toxic gases or liquids in their pure form. Some examples are fluorine (F), chlorine (Cl), and bromine (Br). The halogens are also very reactive and are rarely found in pure form. When combined with alkali metals, they form salts such as sodium chloride (NaCl) and potassium chloride (KCl).

### Noble gases

He 2
Ne 10
Ar 18

On the far right of the periodic table are the **noble gases**, including the elements helium (He), neon (Ne), and argon (Ar). These elements do not naturally form chemical bonds with other atoms and are almost always found in their pure state. They are sometimes called *inert gases* for this reason.

### Transition metals

Ti 22
Fe 26
Cu 29

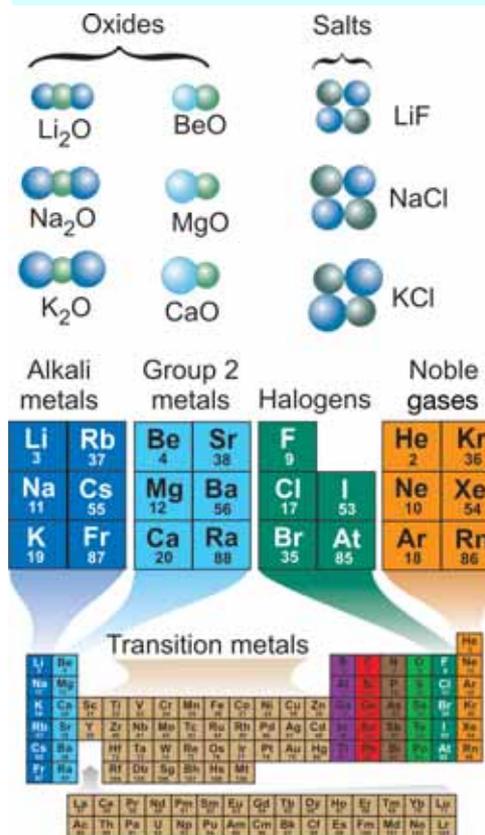
In the middle of the periodic table are the transition metals, including titanium (Ti), iron (Fe), and copper (Cu). These elements are usually good conductors of heat and electricity. For example the wires that carry electricity in your school are made of copper.

## VOCABULARY

**alkali metals** - elements in the first group of the periodic table.

**halogens** - elements in the group containing fluorine, chlorine, and bromine, among others.

**noble gases** - elements in the group containing helium, neon, and argon, among others.





## Energy levels and the periodic table

- The periodic table** The periods (rows) of the periodic table correspond to the energy levels in the atom (Figure 7.4). The first energy level can accept up to two electrons. Hydrogen has one electron and helium has two. These two elements complete the first period.
- Row 2 is the second energy level** The next element, lithium (Li), has three electrons. Lithium begins the second period because the third electron goes into the second energy level. The second energy level can hold eight electrons so there are eight elements in the second row of the periodic table, ending with neon. Neon (Ne) has 10 electrons, which completely fills the second energy level.
- Row 3 is the third energy level** Potassium (K) has 11 electrons, and starts the third period because the eleventh electron goes into the third energy level. We know of elements with up to 118 electrons. These elements have their outermost electrons in the seventh energy level.
- Outer electrons** As we will see in the next chapter, the outermost electrons in an atom are the ones that interact with other atoms. The outer electrons are the ones in the highest energy level. Electrons in the completely filled inner energy levels do not participate in forming chemical bonds.

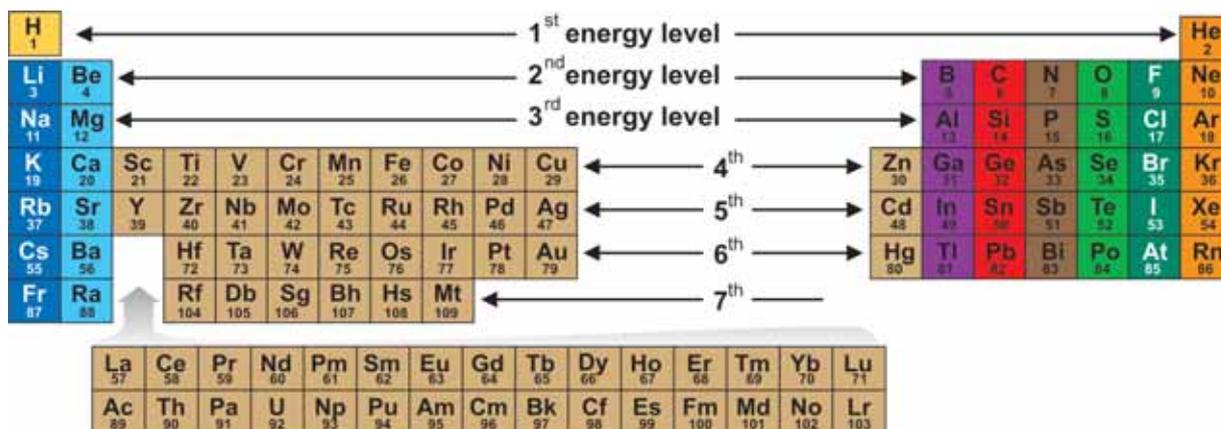
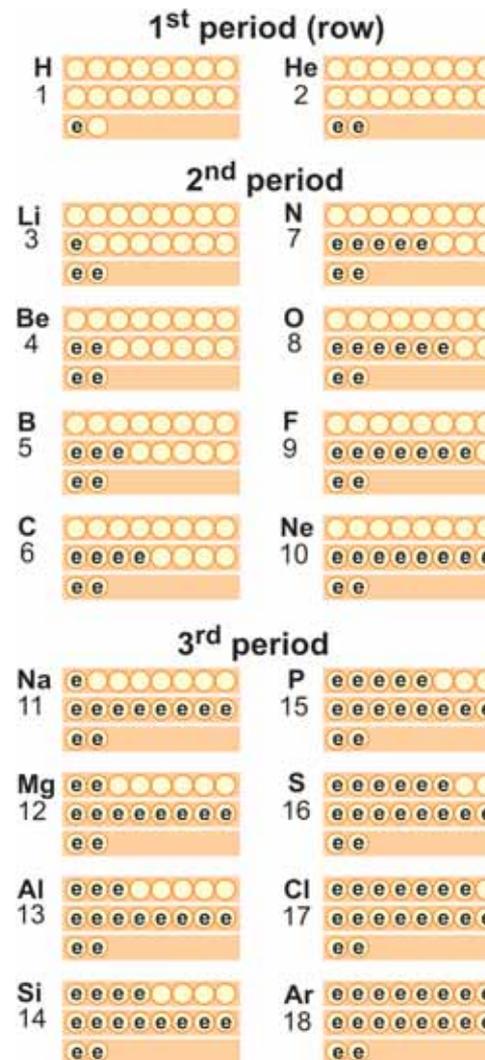
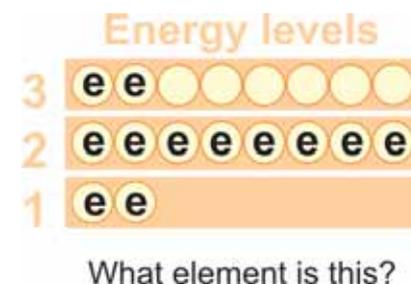


Figure 7.4: The rows (periods) of the periodic table correspond to the energy levels for the electrons in an atom.

## 7.1 Section Review

- Which of the following (pick 2) are physical properties of matter and NOT chemical properties?
  - melts at 650°C
  - density of 1.0 g/ml
  - forms molecules with two oxygen atoms
- Groups of the periodic table correspond to elements with
  - the same color
  - the same atomic number
  - similar chemical properties
  - similar numbers of neutrons
- Which element is the atom in Figure 7.5?
- Name three elements which have similar chemical properties to oxygen.
- The atomic mass unit (amu) is
  - the mass of a single atom of carbon
  - one millionth of a gram
  - approximately the mass of a proton
  - approximately the mass of electron
- What element belongs in the empty space in Figure 7.6?
- The outermost electrons of the element vanadium (atomic #23) are in which energy level of the atom? How do you know?
- The elements fluorine, chlorine and, bromine are in which group of the periodic table?
  - the alkali metals
  - the oxygen-like elements
  - the halogens
  - the noble gases
- What three metals are in the third period (row) of the periodic table?



**Figure 7.5:** Question 3

			He 2
N 7	O 8	F 9	Ne 10
P 15	S 16	?	Ar 18
As 33	Se 34	Br 35	Kr 36
Sb 51	Te 52	I 53	Xe 54

**Figure 7.6:** Which element belongs in the empty space (question 6)?



## 7.2 Properties of the elements

The elements have a wide variety of chemical and physical properties. Some are solid at room temperature, like copper. Others are liquid (like bromine) or gas (like oxygen). Some solid elements (like zinc) melt at very low temperatures and some melt at very high temperatures (like titanium). Chemically, there is an equally wide variety of properties. Some elements, like sodium, form salts that dissolve easily in water. Other elements, like neon do not form compounds with any other elements.

### Room temperature appearance

**Most elements are solid at room temperature**

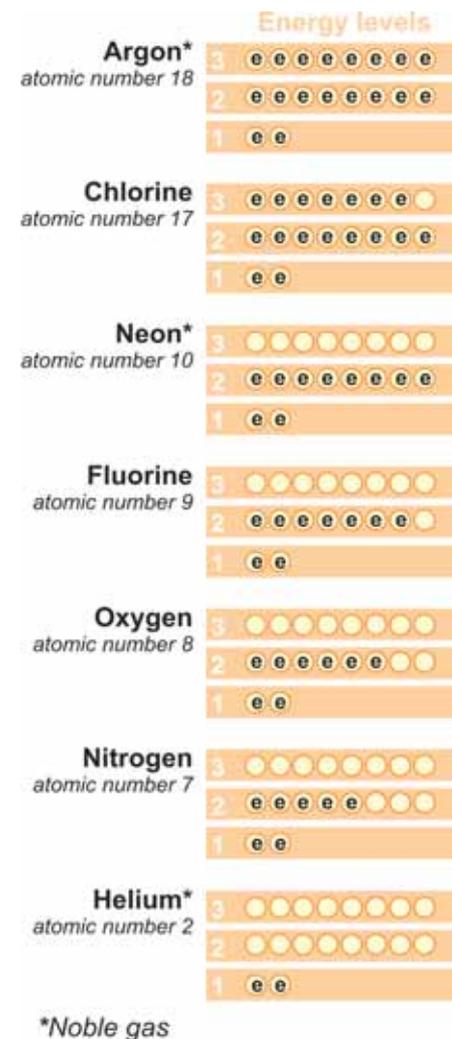
Most of the pure elements are solid at room temperature. Only 11 of the 92 naturally occurring elements are a gas, and 10 of the 11 are found on the far right of the periodic table. Only 2 elements (Br and Hg) are liquid at room temperature.

**What this tells us about intermolecular forces**

An element is solid when intermolecular forces are strong enough to overcome the thermal motion of atoms. At room temperature, this is true for most of the elements. The noble gases and elements to the far right of the periodic table are the exception. *These elements have completely filled or nearly filled energy levels* (Figure 7.7). When an energy level is completely filled, the electrons do not interact strongly with electrons in other atoms, reducing intermolecular forces.

**Room temperature phases of the elements**

<span style="border: 1px solid black; padding: 2px;">S</span> Solid <span style="border: 1px solid black; padding: 2px;">L</span> Liquid <span style="border: 1px solid black; padding: 2px;">G</span> Gas																																															
H 1																	He 2																														
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10																														
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18																														
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36																														
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54																														
Cs 55	Ba 56											Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86																													
Fr 87	Ra 88	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109																																								
<table border="1" style="width: 100%; border-collapse: collapse; text-align: center; margin-top: 10px;"> <tr> <td style="border: 1px solid black;">La 57</td> <td style="border: 1px solid black;">Ce 58</td> <td style="border: 1px solid black;">Pr 59</td> <td style="border: 1px solid black;">Nd 60</td> <td style="border: 1px solid black;">Pm 61</td> <td style="border: 1px solid black;">Sm 62</td> <td style="border: 1px solid black;">Eu 63</td> <td style="border: 1px solid black;">Gd 64</td> <td style="border: 1px solid black;">Tb 65</td> <td style="border: 1px solid black;">Dy 66</td> <td style="border: 1px solid black;">Ho 67</td> <td style="border: 1px solid black;">Er 68</td> <td style="border: 1px solid black;">Tm 69</td> <td style="border: 1px solid black;">Yb 70</td> <td style="border: 1px solid black;">Lu 71</td> </tr> <tr> <td style="border: 1px solid black;">Ac 89</td> <td style="border: 1px solid black;">Th 90</td> <td style="border: 1px solid black;">Pa 91</td> <td style="border: 1px solid black;">U 92</td> <td style="border: 1px solid black;">Np 93</td> <td style="border: 1px solid black;">Pu 94</td> <td style="border: 1px solid black;">Am 95</td> <td style="border: 1px solid black;">Cm 96</td> <td style="border: 1px solid black;">Bk 97</td> <td style="border: 1px solid black;">Cf 98</td> <td style="border: 1px solid black;">Es 99</td> <td style="border: 1px solid black;">Fm 100</td> <td style="border: 1px solid black;">Md 101</td> <td style="border: 1px solid black;">No 102</td> <td style="border: 1px solid black;">Lr 103</td> </tr> </table>																		La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71	Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103
La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71																																	
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103																																	



**Figure 7.7:** The noble gases have completely filled energy levels. All of the elements which are gas at room temperature have filled or nearly filled energy levels.

## Periodic properties of the elements

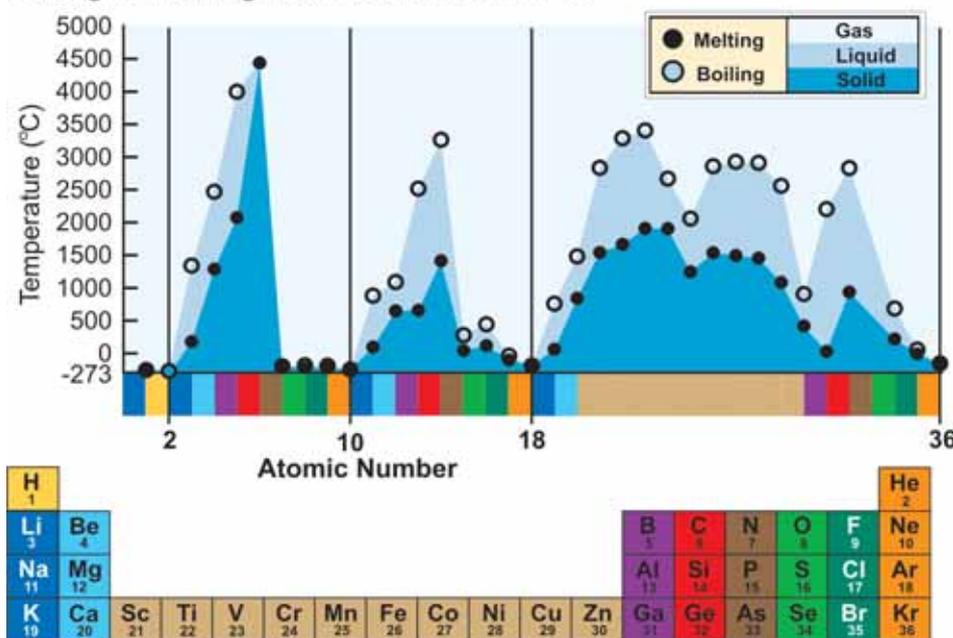
### The pattern in melting and boiling points

We said earlier that the periodic table arranges elements with common properties in groups (columns). The diagram below shows the melting and boiling points for the first 36 elements. The first element in each row always has a low melting point (Li, Na, K). The melting (and boiling) points rise toward the center of each row and then decrease again.

### Periodicity

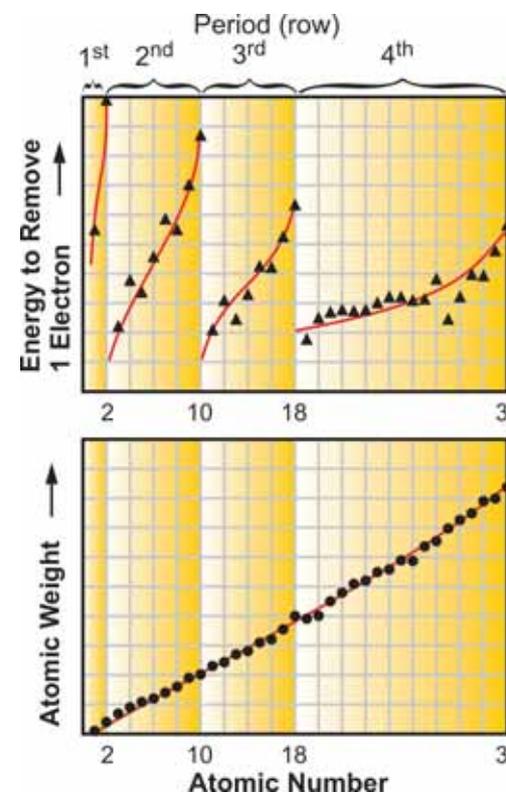
The pattern of melting and boiling points is an example of **periodicity**. Periodicity means properties repeat each period (row) of the periodic table. Periodicity indicates that a property is strongly related to the filling of electron energy levels. Melting points reflect the strength of intermolecular forces. The diagram shows that intermolecular forces are strongest when energy levels are about half full (or half empty). Elements with half filled energy levels have the greatest number of electrons that can participate in bonding.

Melting and Boiling Points for Elements 1 - 36



## VOCABULARY

**periodicity** - the repeating pattern of chemical and physical properties of the elements.

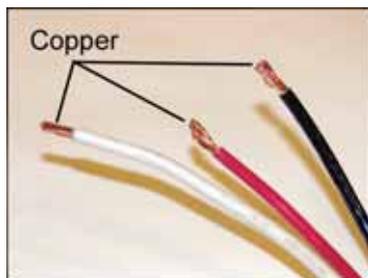


**Figure 7.8:** One of these graphs shows periodicity and the other does not. Can you tell which one is periodic? The top graph shows the energy it takes to remove an electron. The bottom graph shows the atomic weight.



## Thermal and electrical conductivity

Metals are good electrical conductors



Electricity is something we often take for granted because we use it everyday. Fundamentally, electricity is the movement of electric charge, usually electrons. Some materials allow electrons to flow easily through them. If you connected a battery and a bulb through one of these materials the bulb would light. We call these materials **electrical**

**conductors**. Copper and aluminum are excellent electrical conductors. Both belong to the family of metals, which are elements in the center and left-hand side of the periodic table (Figure 7.9). Copper and aluminum are used for almost all electrical wiring.

Metals are good conductors of heat



If you hold one end of a copper pipe with your hand and heat the other end with the torch, your hand will quickly get hot. That is because copper is a good conductor of heat as well as electricity. Like copper, most metals are good **thermal**

**conductors**. That is one reason pots and pans are made of metal. Heat from a stove can pass easily through the metal walls of a pot to transfer energy to the food inside.

Nonmetals are typically insulators



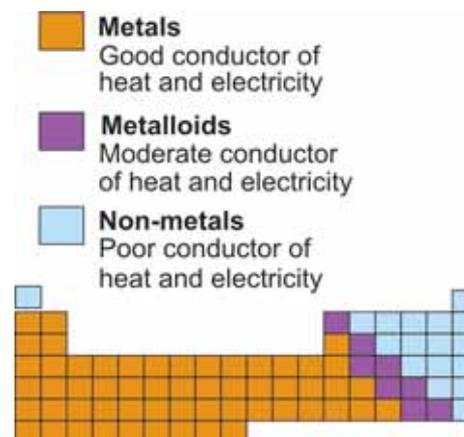
Elements to the far right of the periodic table are not good conductors of electricity or heat especially as many are a gas. Because they are so different from metals, these elements are called non-metals. Nonmetals make good **insulators**. An insulator is a material which slows down or stops the flow of either heat or electricity. Air is a good insulator. Air is oxygen, nitrogen and argon.

### VOCABULARY

**electrical conductor** - a material that allows electricity to flow through easily.

**thermal conductor** - a material that allows heat to flow easily.

**insulator** - a material that slows down or stops the flow of either heat or electricity.



**Figure 7.9:** Dividing the periodic table up into metals, metalloids, and non-metals.

## Metals and metal alloys

### Steel is an alloy of iron and carbon

When asked for an example of a metal, many people immediately think of **steel**. Steel is made from iron which is the fourth most abundant element in the Earth's crust. However, steel is not pure iron. Steel is an *alloy*. An alloy is a solid mixture of one or more elements. Most metals are used as alloys and not in their pure elemental form. Common steel contains mostly iron with a few percent of carbon. Stainless steel and high strength steel alloys also contain small percentages of other elements such as chromium, manganese, and vanadium. More than 500 different types of steel are in everyday use (Figure 7.10).

### Aluminum is light

Aluminum is a metal widely used for structural applications. Aluminum alloys are not quite as strong as steel however aluminum has one third the density of steel. Aluminum alloys are used when weight is a factor, such as for airplane construction. The frames and skins of airplanes are built of aluminum alloys (Figure 7.11).

### Titanium is both strong and light



Titanium combines the strength and hardness of steel with the light weight of aluminum. Titanium alloys are used for military aircraft, racing bicycles, and other high performance machines. Titanium is expensive because it is somewhat rare and difficult to work with.

### Brass



Brass is a hard, gold-colored metal alloy. Ordinary (yellow) brass is an alloy of 72% copper, 24% zinc, 3% lead, and 1% tin. Hinges, door knobs, keys and decorative objects are made of brass because brass is easy to work with. Because it contains lead however, you should never eat or drink from anything made of ordinary (yellow) brass.

## VOCABULARY

**steel** - an alloy of iron and carbon.



Stainless steel kitchen knife  
(does not rust)



Ordinary steel nails (will rust)

**Figure 7.10:** Nails are made of steel which contains 95% iron and 5% carbon. Kitchen knives are made of stainless steel which is an alloy containing vanadium and other metals.



**Figure 7.11:** This aircraft is made mostly from aluminum alloys. Aluminum combines high strength and light weight.

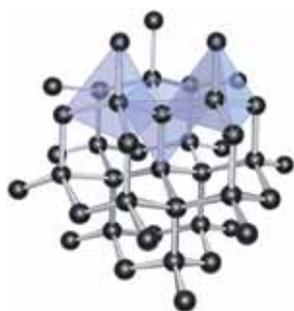


## Carbon and carbon-like elements

### Carbon is an important element for life

Carbon represents less than 100th of a percent of the earth's crust by mass, yet it is the element most essential for life on our planet. Virtually all the molecules that make up plants and animals are constructed around carbon. The chemistry of carbon is so important it has its own name, organic chemistry, which is the subject of Chapter 11 (Figure 7.12).

### Diamond and graphite



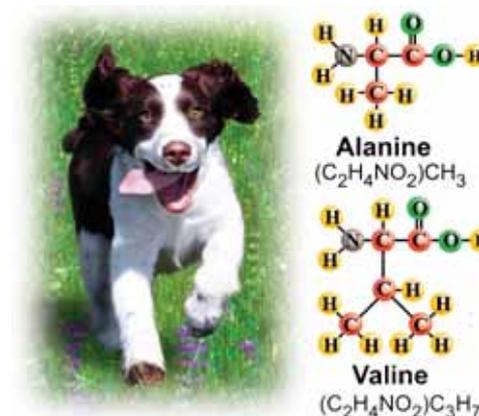
Pure carbon is found in nature in two very different forms. Graphite is a black solid made of carbon that becomes a slippery powder when ground up. Graphite is used for lubricating locks and keys. Diamond is also pure carbon. Diamond is the hardest natural substance known and also has the highest thermal conductivity of any material. Diamond is so strong because every carbon atom in diamond is bonded to four neighboring atoms in a tetrahedral crystal.

### Silicon

Directly under carbon on the periodic table is the element silicon. Silicon is the second most abundant element in the Earth's crust second only to oxygen. Like carbon, silicon has four electrons in its outermost energy level. This means silicon can also make bonds with four other atoms. Sand, rocks, and minerals are predominantly made from silicon and oxygen (Figure 7.13). Most gemstones, such as rubies and emeralds, are compounds of silicon and oxygen with traces of other elements. In fact, if you can see a glass window you are looking at (or through) pure silica ( $\text{SiO}_2$ ).

### Silicon and semiconductors

Perhaps silicon's most famous application today is for making semiconductors. Virtually every computer chip or electronic device uses crystals of very pure silicon (Figure 7.14). The area around San Jose, California is known as Silicon Valley because of the electronics companies located there. Germanium, the element just below silicon on the periodic table is also used for semiconductors.



**Figure 7.12:** Organic chemistry is the chemistry of living organisms and is based on the element carbon.



**Figure 7.13:** Sand and glass are two common materials based on silicon.

**Figure 7.14:** Microelectronics (the small black squares) are constructed on crystals of pure silicon.



## Nitrogen, Oxygen and Phosphorus

### Nitrogen and oxygen make up most of the atmosphere

Nitrogen is a colorless tasteless and odorless gas that makes up 78 percent of Earth's atmosphere. Oxygen makes up another 21 percent of the atmosphere. Both oxygen and nitrogen gas consist of molecules with two atoms ( $N_2$ ,  $O_2$ ).

### Oxygen in rocks and minerals

Oxygen is only 21 percent of the atmosphere however, Oxygen is by far the most abundant element in Earth's crust. Almost 46 percent of the Earth's crust is oxygen. Because it is so reactive, all of this oxygen is bonded to other elements in rocks and minerals in the form of oxides. Silicon dioxide ( $SiO_2$ ), calcium oxide ( $CaO$ ), aluminum oxide ( $Al_2O_3$ ), and magnesium oxide ( $MgO$ ) are common mineral compounds. Hematite, an oxide of iron ( $Fe_2O_3$ ) is a common ore from which iron is extracted.

### Liquid nitrogen

With a boiling point of  $-196^\circ C$ , liquid nitrogen is used for rapid freezing in medical and industrial applications. A common treatment for skin warts is to freeze them with liquid nitrogen.

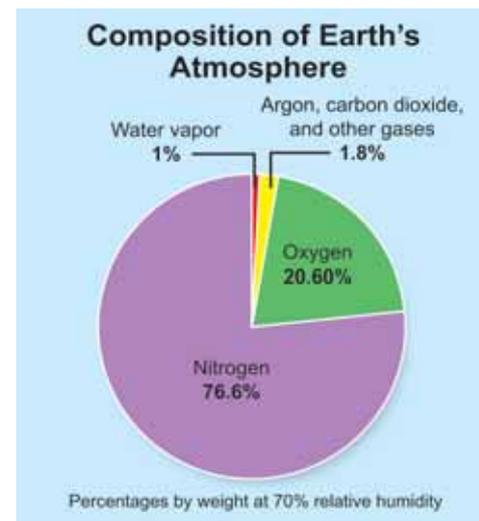
### Oxygen and nitrogen in living organisms

Oxygen and nitrogen are crucial to living animals and plants. For example, proteins and DNA both contain nitrogen. Nitrogen is part of a key ecological cycle. Bacteria in soil convert nitrogen dioxide ( $NO_2$ ) in the soil to complex proteins and amino acids. These nutrients are taken up by the roots of plants, and later eaten by animals. Waste and dead tissue from animals is recycled by the soil bacteria which return the nitrogen to begin a new cycle.

### Phosphorus



Directly below nitrogen in the periodic table is phosphorus. Phosphorus is a key ingredient of DNA, the molecule responsible for carrying the genetic code in all living creatures. One of phosphorus' unusual applications is in "glow-in-the-dark plastic". When phosphorus atoms absorb light, they store energy and give off a greenish glow as they slowly re-emit the energy.



**Figure 7.15:** *The Earth's atmosphere is predominantly nitrogen and oxygen.*



**Figure 7.16:** *Oxygen makes up 46% of the mass of Earth's crust. This enormous quantity of oxygen is bound up in rocks and minerals.*



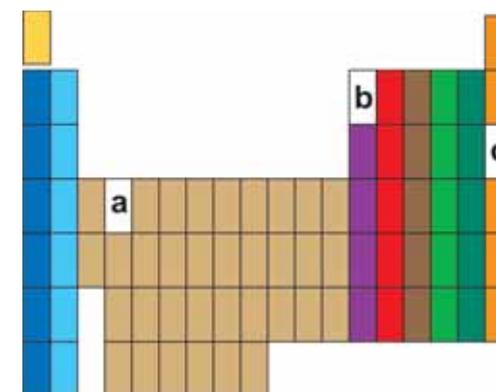
## 7.2 Section Review

- Name two elements that are liquid at room temperature.
- Which of the following is NOT true about the noble gases?
  - they have completely filled energy levels,
  - they have weak intermolecular forces
  - they do not bond with other elements in nature
  - they have boiling points above room temperature
- Describe what it means if a chemical or physical property is periodic.
- Name three elements which are good conductors of electricity.
- Name three elements which are good conductors of heat.
- A metalloid is an element which
  - has properties between those of a metal and a nonmetal
  - is a good thermal conductor but a poor electrical conductor
  - is a good electrical conductor but a poor thermal conductor
  - belongs to the same group as carbon in the periodic table
- Steel is a metallic-like material but is not a pure element. What is steel?
- Almost all of the oxygen on the planet Earth is found in the atmosphere. Is this statement true or false?
- This element is abundant in Earth's crust and combines with oxygen to form rocks and minerals. Which element is it?
- An element which has strong intermolecular forces is most likely to have
  - a boiling point below room temperature
  - a melting point below room temperature
  - a boiling point very close to its melting point
  - a very high melting point
- Which element in Figure 7.17 is likely to be a good conductor of electricity?
- Which element in Figure 7.17 is likely to be an insulator?



### CHALLENGE

One of the elements with atomic number less than 54 does not exist in nature. It was created in the laboratory. Which element is this and how was it discovered?



**Figure 7.17:** What are the properties of these three elements? (questions 11 and 12)



## Naming the Elements

Spend more than a few minutes looking at the periodic table and you'll probably start to wonder who on Earth came up with some of the element names. Yttrium, for example. How did anyone think that up?

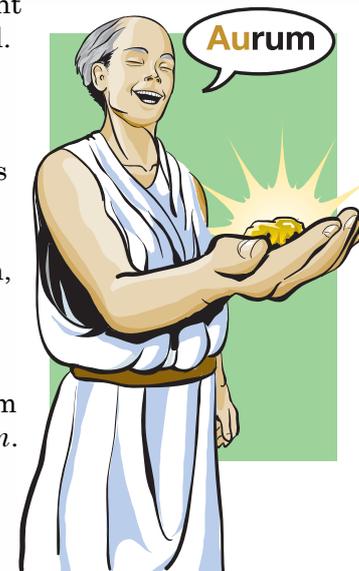
The elements' chemical symbols are just as confusing. Sure, it's easy to see why O stands for oxygen, but why did they pick W for tungsten and K for potassium?

### Origin of unusual element symbols

Element	Symbol	Reason
Sodium	Na 11	<i>Natrium</i> (Latin). The Romans used <i>natrum</i> , from an Egyptian term.
Potassium	K 19	<i>Kalium</i> (Latin). From an Arabic term meaning "to roast," because potassium is found in plant ashes.
Iron	Fe 26	<i>Ferrum</i> (Latin). From an ancient Semitic word.
Silver	Ag 47	<i>Argentum</i> (Latin). Related to the Sanskrit word for "shining brightly."
Tin	Sn 50	<i>Stannum</i> (Latin). From Indo-European term meaning "to drip" (tin has a low melting point).
Antimony	Sb 51	<i>Stibium</i> (Latin). From an Ancient Egyptian word for the eyebrow make-up they made from $Sb_2S_3$ .
Tungsten	W 74	<i>Wolfram</i> (German). The word means "wolf's foam." The mineral wolframite "eats" tin during extraction like a wolf eats sheep.
Gold	Au 79	<i>Aurum</i> (Latin). From the word for yellow.
Mercury	Hg 80	<i>Hydrargyrum</i> (Latin). From the Greek words for water and silver.
Lead	Pb 82	<i>Plumbum</i> (Latin). Probably from a term used in the Aegean area before the time of the Greeks.

### Ancient names

It turns out the history of element names is messy and complicated. On the one hand, you have elements whose existence was well-known in many cultures long before the periodic table was developed. Gold is a good example. There are hundreds of names, both ancient and modern, for this element. The English word *gold* comes from the German word for yellow. The element's symbol, Au, comes from the Latin word for yellow, *aurum*.



### Modern names

On the other hand, you have elements that have yet to be discovered (or synthesized in a lab). The naming system for these is based on their number in the periodic table. Take element number 118, for example. It's called ununoctium. In English, that translates to "one-one-eight-ium." Using the table below, can you name element 114?

Table 7.1: IUPAC naming system for new elements

digit	syllable	digit	syllable
0	nil	6	hex
1	un	7	sept
2	bi	8	oct
3	tri	9	en
4	quad	suffix	-ium (place at end of name)
5	pent		

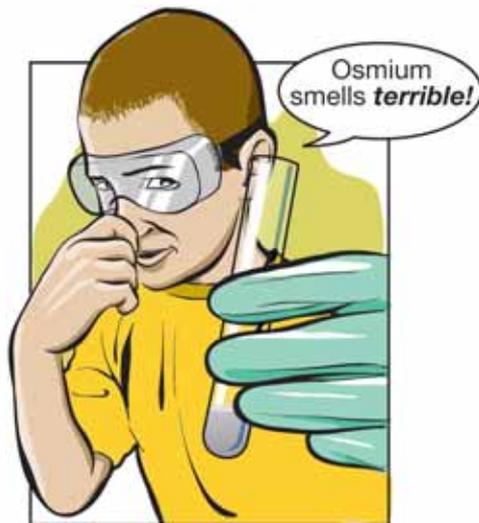
## The names in between

In between the ancient and the undiscovered elements is a long list of elements that were identified, for the most part, between 1600 and 1970. Some of these elements are named for places. Yttrium, for example, is named for Ytterby, a feldspar quarry near Stockholm, Sweden. Yttrium was first isolated from Ytterby rocks.

Some of the elements' names are descriptive. Chlorine (from *khloros*, for yellow-green), iodine (from *ioeides*, for violet) and rhodium (from *rhodon*, for rose) are names derived from the Greek word for the element's color.

The glow-in-the-dark element phosphorus' name means "light bearing" in Greek. The name hydrogen means "water producing." It was suggested by Antoine Lavoisier because when hydrogen burns, water is produced.

One descriptive name reflects an unpleasant characteristic: The element name osmium is taken from the Greek word *osme*, which means "odor." The element got its name because one of its common compounds,  $\text{OsO}_4$ , smells terrible!



## Official naming rights

Since 1949, the International Union for Pure and Applied Chemistry (IUPAC), based in Oxford, England, has been responsible for the international names for the elements. These names are used when chemicals are sold from one country to another. However, countries can use their own names within their borders—and many countries do, especially those that do not use the English alphabet in their native language.

When a new element is identified, the discoverers are awarded the privilege of proposing a name. This is not always a straightforward process, since some of the heaviest elements exist for only fractions of a second. When several labs in different parts of the world are working on similar projects, it can be difficult to determine who should get credit for being first.

However, the elements up through element 109, meitnerium, now have official IUPAC names. Some of these names you will recognize as familiar figures from your study of modern physics. Others, like hassium and dubnium, are named after places where the elements were synthesized. Perhaps in your lifetime you will have a hand in naming a new element!

## Questions:

1. Take a look at the periodic table. How many elements can you find that are named after scientists you have studied?
2. The names for cerium and palladium have something in common. Use a library or the internet to find out the origin of these names and explain their relationship.
3. Three competing groups proposed names for elements 104 to 108. Find out who they were and how the IUPAC finally resolved the controversy in 1997.

**CHAPTER  
ACTIVITY****Name That Element**

Each element on the periodic table has a chemical symbol that is an abbreviation of the element's name. Unlike the abbreviations for a U.S. state, these symbol-abbreviations are not always obvious. Many are derived from the element's name in a language such as Latin or German. The chemical symbol for silver is "Ag". Note that the first letter in the symbol is upper case and the second is lower case. Writing symbols this way allows us to represent all of the elements without getting confused. There is a big difference between the element cobalt, with its symbol Co, and the compound carbon monoxide, written as CO. In this activity, you'll make a set of flashcards for 30 elements and then play a game to see who in your class knows their elements.

**Materials:**

30 blank 8 × 10 cards and markers

**What you will do**

- Each person in the class writes the symbol of one of the elements from the list on one of the large cards. Make sure you write the chemical symbol large enough so you can see it all the way across the classroom. The elements suggested below are some of the most common elements.

C	Cu	O	N	He
H	Cl	Mg	Na	K
S	Ca	Mn	Fe	Br
B	Cs	Ag	Au	Pb
I	Si	Al	F	Ne
Ba	Be	Cr	Ni	Hg

- The teacher collects all the cards and stands in front of the class.
- The first two players stand next to each other. The teacher holds up a chemical symbol card and the first player to correctly give the name of the element moves on to the next player. The player who didn't answer sits down.
- The game goes all the way around the classroom, with the player who names the element moving on and the other player sitting down.
- The player who is left standing at the end of the game is the winner.

**Applying your knowledge**

- Find the element whose chemical symbol comes from the Latin word *aurum* which means "shining dawn".
- What word does the chemical symbol for lead, Pb, come from?
- Find the element whose chemical symbol comes from the Latin word *natrium*?
- Which element comes from the Latin word for coal?
- Another game to play is to see who can come up with the longest word spelled completely with chemical symbols. Some examples are *life*, from lithium (Li) and iron (Fe), and *brook*, from bromine (Br), oxygen (O), and potassium (K).

# Chapter 7 Assessment

## Vocabulary

Select the correct term to complete the sentences.

physical properties	periodic table	metal
period	group	alloy
nonmetal	atomic weight	noble gases
alkali	halogens	insulators
periodicity	atomic mass unit	thermal conductor
steel	electrical conductor	

### Section 7.1

1. Elements that are poor conductors of heat and electricity are classified as \_\_\_\_.
2. A mass equal to  $\frac{1}{12}$  the mass of a carbon-12 atom is the \_\_\_\_.
3. Characteristics of matter that can be seen through direct observation such as density, melting point, and boiling point are called \_\_\_\_.
4. Elements in the first group of the periodic table are the \_\_\_\_.
5. Elements grouped as a column on the periodic table belong to a(n) \_\_\_\_.
6. Elements that are typically shiny and good conductors of heat and electricity are classified as \_\_\_\_.
7. The group containing fluorine, chlorine, and bromine are called the \_\_\_\_.
8. A chart which organizes the elements by chemical properties is known as the \_\_\_\_.
9. The average mass, measured in amu, of all the isotopes of an element is called the \_\_\_\_.
10. Elements grouped as a row on the periodic table belong to a(n) \_\_\_\_.
11. Elements in the group containing helium, sometimes called the inert gases, are known as \_\_\_\_.

### Section 7.2

12. A material that allows heat to flow through easily is known as a(n) \_\_\_\_.
13. An alloy made by combining iron and carbon is \_\_\_\_.
14. A material that slows or stops the flow of heat or electricity is a(n) \_\_\_\_.
15. The repeating pattern of physical and chemical properties displayed by elements on different periods of the periodic table is known as \_\_\_\_.
16. A solid mixture of metallic elements is known as a(n) \_\_\_\_.
17. A material that allows electricity to flow through easily is known as a(n) \_\_\_\_.

## Concepts

### Section 7.1

1. List five physical properties of an element.
2. State one important difference between a physical change and a chemical change.
3. What property of elements was used to organize the periodic table?
4. How are the terms group and period used on the periodic table?
5. What is the general location of metals on the periodic table?
6. The energy level of the outermost electrons in an element is the same as the \_\_\_\_ number for that element.

