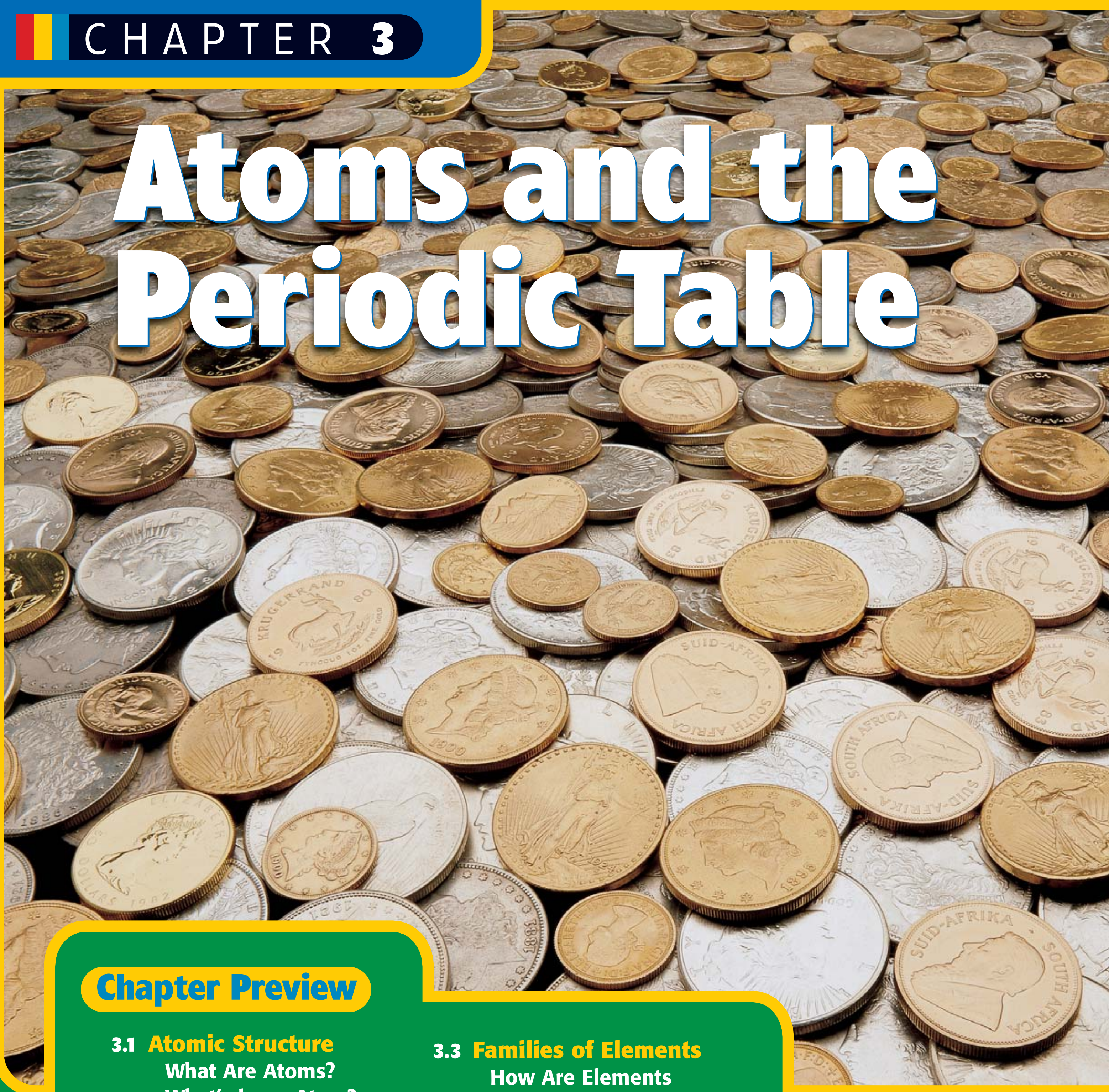
CHAPTER 3

Atoms and the Periodic Table



Chapter Preview

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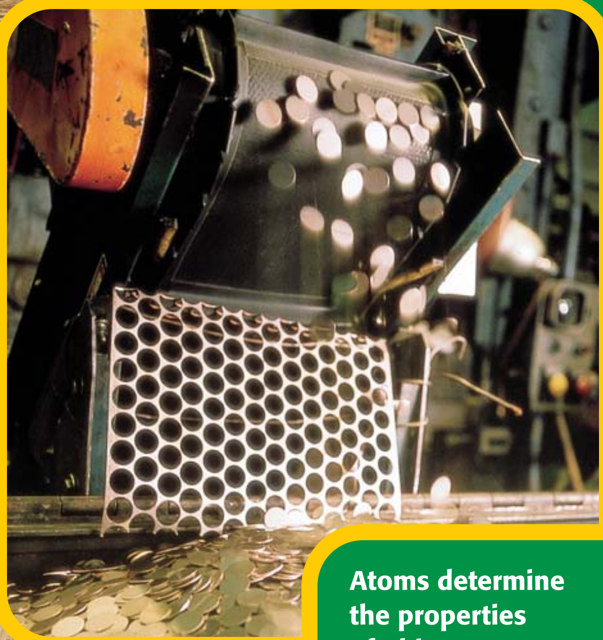

Atoms determine the properties of objects. For example, metal atoms give these coins their shine and their ability to be pressed flat by this stamping press.

Focus ACTIVITY

Background Have you ever wondered why coins shine? Coins shine because they are made of metals that reflect light. Another property of metals is that they do not shatter. Metals bend as they are pressed into thin, flat sheets during the coin-making process. All metals share some similarities, but each metal has its own unique chemical and physical properties.

Metals, like everything around us, are made of trillions of tiny units that are too small to see called atoms. Atoms determine the properties of all substances. For example, gold atoms make gold coins softer and shinier than silver coins, which are made of silver atoms. Pennies get their color from the copper atoms they are coated with. In this chapter, you will learn what determines an atom's properties, why atoms are considered the smallest units of elements, and how elements are classified.

Activity 1 What metals do you see during a typical day? Describe their uses and their properties.

Activity 2 Describe several different ways to classify the coins shown on the opposite page.

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Atomic Structure

KEY TERMS

nucleus
proton
neutron
electron
energy level
orbital
valence electron

OBJECTIVES

- Explain Dalton's atomic theory, and describe why it was more successful than Democritus's theory.
- State the charge, mass, and location of each part of an atom according to the modern model of the atom.
- Compare and contrast Bohr's model with the modern model of the atom.

Atoms are all around you. They make up the air you are breathing, the chair you are sitting in, and the clothes you are wearing. This book, including this page you are reading, is also made of atoms.

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc One, Module 2:
Models of the Atom
Use the Interactive Tutor to learn more about this topic.

What Are Atoms?

Atoms are tiny units that determine the properties of all matter. The aluminum cans shown in **Figure 3-1** are lightweight and easy to crush because of the properties of the atoms that make up the aluminum.

Our understanding of atoms required many centuries

In the fourth century B.C., the Greek philosopher Democritus suggested that the universe was made of invisible units called atoms. The word *atom* is derived from the Greek word meaning "unable to be divided." He believed movements of atoms caused the changes in matter that he observed.

Although Democritus's theory of atoms explained some observations, Democritus was unable to provide the evidence needed to convince people that atoms really existed. Throughout the centuries that followed, some people supported Democritus's theory. But other theories were also proposed. As the science of chemistry was developing in the 1700s, more emphasis was put on making careful and repeated measurements in scientific experiments. As a result, more-reliable data were collected that were used to favor one theory over another.

Aluminum Atoms

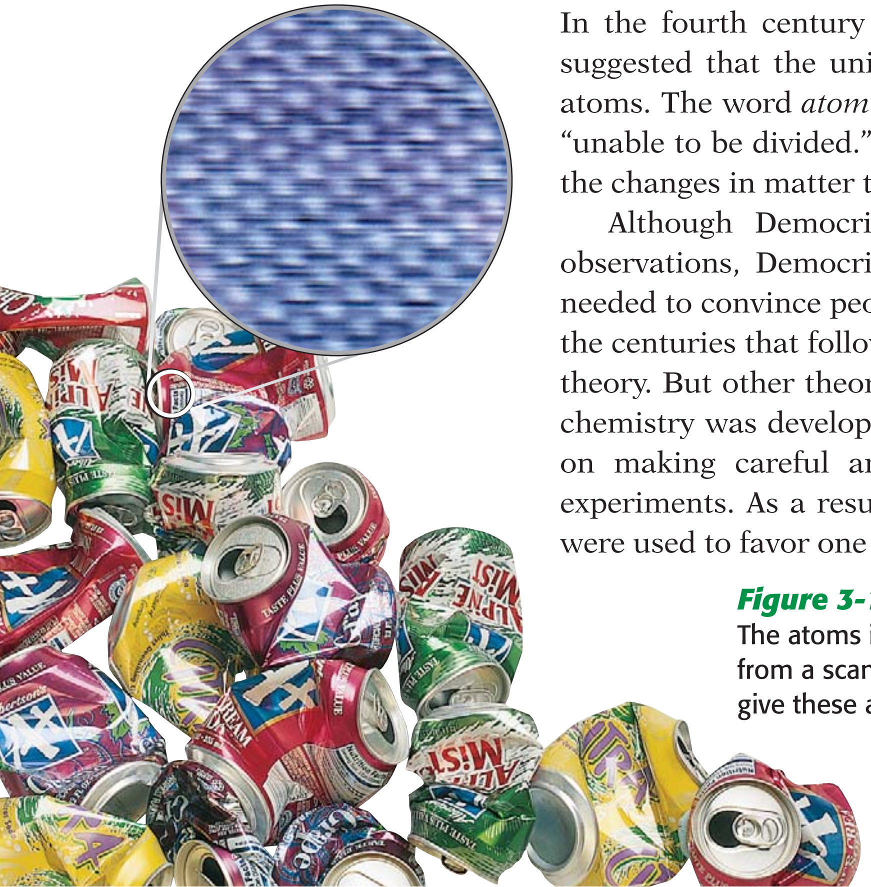

Figure 3-1
The atoms in aluminum, seen here as an image from a scanning tunneling electron microscope, give these aluminum cans their properties.

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Atoms are the building blocks of molecules

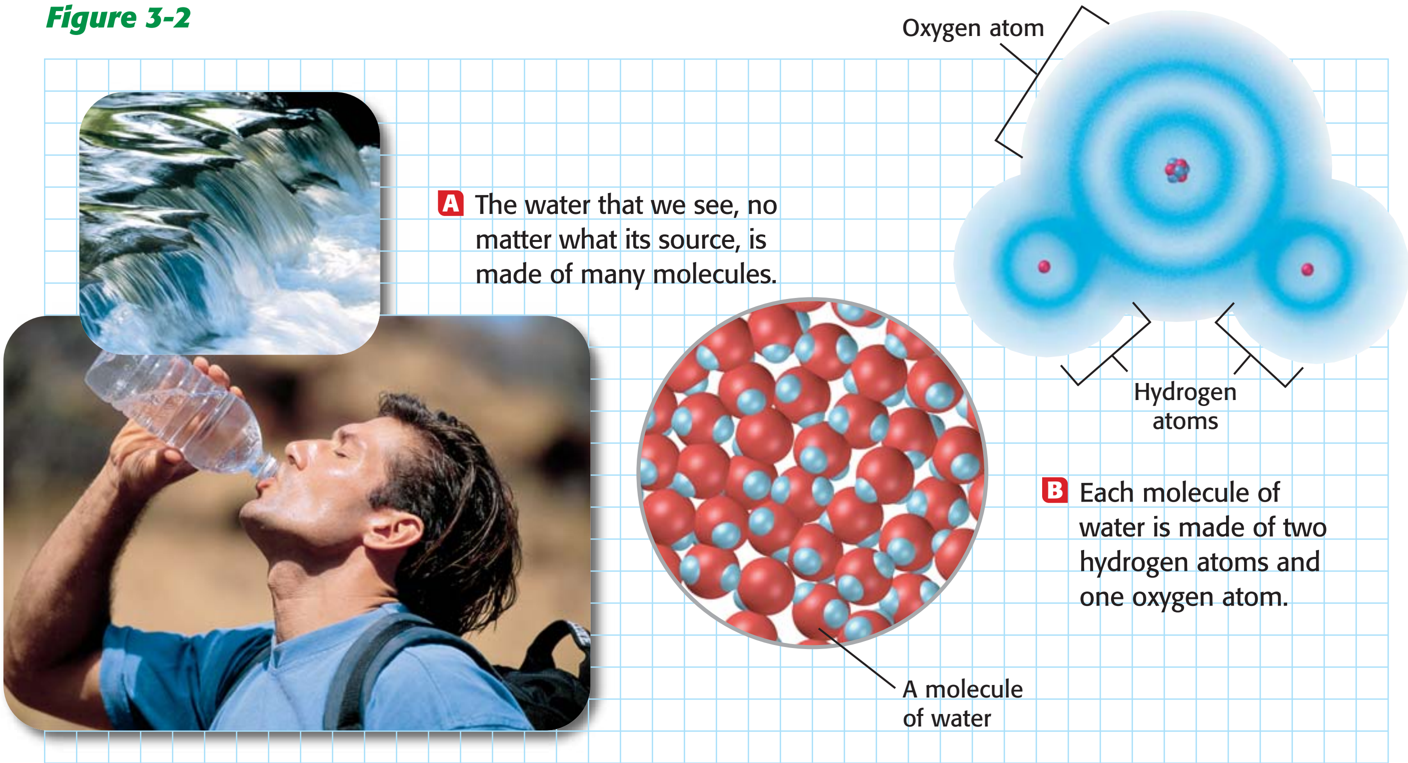
In 1808, an English schoolteacher named John Dalton proposed his own atomic theory. Dalton's theory was widely accepted because there was much evidence to support it. In his theory, Dalton proposed the following:

- **Every element is made of tiny, unique particles called atoms that cannot be subdivided.**
- **Atoms of the same element are exactly alike.**
- **Atoms of different elements can join to form molecules.**

An atom is the smallest part of an element that still has the element's properties. Imagine dividing a coin made of pure copper until the pieces were too small for you to see. If you were able to continue dividing these pieces, you would be left with the simplest units of the coin—copper atoms. All the copper atoms would be exactly alike. Each copper atom would have chemical properties mostly the same as the coin you started with.

You learned in Chapter 2 that atoms can join. **Figure 3-2** shows how atoms join to form molecules of water. The water we see is actually made of a very large number of water molecules. Whether it gushes downstream in a riverbed or is bottled for us to drink, water is always the same: each molecule is made of two hydrogen atoms and one oxygen atom.

Figure 3-2



What's in an Atom?

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nucleus the center of an atom; made up of protons and neutrons

proton a positively charged subatomic particle in the nucleus of an atom

neutron a neutral subatomic particle in the nucleus of an atom

electron a tiny negatively charged subatomic particle moving around outside the nucleus of an atom

VOCABULARY Skills Tip

Remember that **pro**tons *have a* ***positive*** *charge and* **neut**rons *are* ***neutral.***

Less than 100 years after Dalton published his atomic theory, scientists determined that atoms could be split, or broken down even further. While we now know that there are many different subatomic particles making up atoms, only three of these are involved in the everyday chemistry of most substances.

Atoms are made of protons, neutrons, and electrons

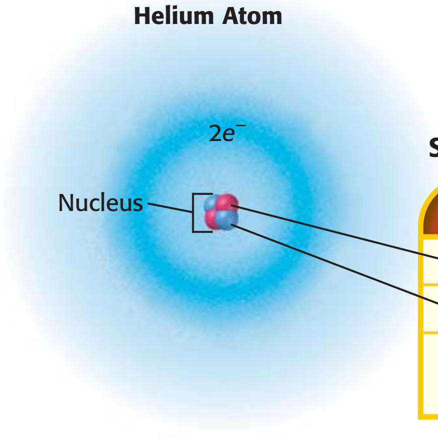
At the center of each atom is a small, dense **nucleus** with a positive electric charge. The nucleus is made of **protons** and **neutrons.** These two subatomic particles are almost identical in size and mass, but protons have a positive charge while neutrons have no charge at all. Moving around outside the nucleus and encircling it is a cloud of very tiny negatively charged subatomic particles with very little mass. These particles are called **electrons.** To get an idea of how far from the nucleus an electron can be, consider this: If the nucleus of a hydrogen atom were the size of a tennis ball, its one electron could be found up to 6.4 km (4 mi) away! A helium atom, shown in **Figure 3-3,** has one more proton and one more electron than a hydrogen atom has. That's because the number of protons and electrons an atom has is unique for each element.

Unreacted atoms have no overall charge

You might be surprised to learn that atoms are not charged even though they are made of charged protons and electrons. Atoms do not have a charge because they have an equal number of protons and electrons whose charges exactly cancel. A helium atom has two protons and two electrons. The atom is neutral because the positive charge of the two protons exactly cancels the negative charge of the two electrons.

Charge of two protons:	+2
Charge of two neutrons:	0
Charge of two electrons:	−2
Total charge of a helium atom:	0

Figure 3-3
A helium atom is made of two protons, two neutrons, and two electrons ($2e^-$).



Subatomic Particles

Particle	Charge	Mass (kg)	Location in the atom
Proton	+1	1.67×10^{-27}	In the nucleus
Neutron	0	1.67×10^{-27}	In the nucleus
Electron	−1	9.11×10^{-31}	Moving around outside the nucleus

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Models of the Atom

Democritus in the fourth century B.C. and later Dalton, in the nineteenth century, thought that the atom could not be split. That theory had to be modified when it was discovered that atoms are made of protons, neutrons, and electrons. Like most scientific models and theories, the model of the atom has been revised many times to explain such new discoveries.

Bohr's model compares electrons to planets

In 1913, the Danish scientist Niels Bohr suggested that electrons in an atom move in set paths around the nucleus much like the planets orbit the sun in our solar system. In Bohr's model, each electron has a certain energy that is determined by its path around the nucleus. This path defines the electron's **energy level.** Electrons can only be in certain energy levels. They must gain energy to move to a higher energy level or lose energy to move to a lower energy level.

One way to imagine Bohr's model is to compare an atom to the stairless building shown in **Figure 3-4.** Imagine that the nucleus is in a very deep basement and that the electronic energy levels begin on the first floor. Electrons can be on any floor of the building but not between floors. Electrons gain energy by riding up in the elevator and lose energy by riding down in the elevator. Higher energy levels are closer together. (Ceiling height decreases toward the top of this modified building.)

According to modern theory, electrons behave more like waves

By 1925, Bohr's model of the atom no longer explained all observations. So a new model was proposed that no longer assumed that electrons orbited the nucleus along definite paths like planets orbiting the sun. In this modern model of the atom, it is believed that electrons behave more like waves on a vibrating string than like particles.

Quick ACTIVITY

Convincing John Dalton

If Dalton were still alive, he might argue: "Atoms are neutral, so they can't be made of charged particles."

Explain why this statement is not true.

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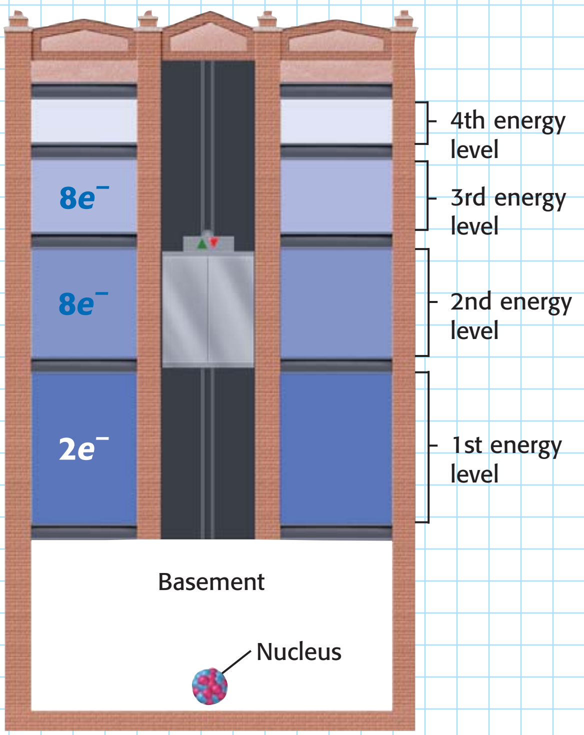
energy level any of the possible energies an electron may have in an atom

Figure 3-4
The energy levels of an atom are like the floors of the building shown here.



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REAL WORLD APPLICATIONS

Designing Drugs In living things, enzymes (compounds that speed up biological reactions) and antibodies (chemical defense agents) use electron arrangements to recognize certain molecules. Because drugs for treating disease and infection are often similar in size and shape to molecules that occur naturally in the body, they can "trick" enzymes and antibodies into behaving in a desired way.

Scientists use computers, along with an equation that represents the wavelike behavior of electrons, to predict the properties of possible new drugs. Computers test how well the drug (shown in yellow in the figure at right) interacts with enzymes and antibodies. Promising compounds are then made. Several prescription medicines on the market today were developed by this process.

Applying Information

Write a paragraph that answers the following questions:

WRITING SKILL

1. Describe how some drugs work.
2. Why are computers used to test certain drugs before they are made?

Imagine the moving blades of a fan, like the one shown in **Figure 3-5.** If you were asked where any one of the blades was located at a certain instant, you would not be able to give an exact answer. In fact, it's nearly impossible to know the exact location of any of the blades because they are moving so quickly. All you know for sure is that each blade could be anywhere within the blurred area you see as the blades turn.

It is also impossible to determine both the exact location of an electron in an atom and its speed and direction. The best scientists can do is calculate the chance of finding an electron in a certain place within an atom. One way to visually show the likelihood of finding an electron in a given location is by shading. The darker the shading, the better the chance of finding an electron at that location. The whole shaded region is called an electron cloud.

Figure 3-5
Just like these blades turning in this fan, the exact positions, speeds, and directions of electrons in an atom cannot be determined.

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Quick ACTIVITY

Constructing a Model

A scientific model is a simplified representation based on limited knowledge that describes how an object looks or functions. In this activity, you will construct your own model.

1. Obtain from your teacher a can that is covered by a sock and sealed with tape. An unknown object is inside the can.
2. Without unsealing the container, try to determine the characteristics of the object inside by examining it through the sock. What is the object's mass? What is its size, shape, and texture? Record all of your observations in a data table.
3. Remove the taped sock so that you can touch the object without looking at it. Record these observations as well.
4. Use the data you have collected to draw a model of the unknown object.
5. Finally remove the object to see what it is. Compare and contrast the model you made with the object it is meant to represent.

Electrons are found in orbitals within energy levels

The regions in an atom where electrons are found are called **orbitals.** Electrons may occupy four different kinds of orbitals within atoms. The simplest kind of orbital is an *s* orbital. An *s* orbital can have only one possible orientation in space because it is shaped like a sphere, as shown in **Figure 3-6.** An *s* orbital's spherical shape enables it to surround the nucleus of an atom.

A *p* orbital, on the other hand, is dumbbell-shaped and can be oriented three different ways in space, as shown in **Figure 3-7.** The axes on the graphs are drawn to help you picture how these orbitals look in three dimensions. Imagine the *z*-axis being flat on the page. Imagine the dotted lines on the *x*- and *y*-axes going into the page, and the darker lines coming out of the page.

The *d* and *f* orbitals are much more complex. There are five possible *d* orbitals and seven possible *f* orbitals. Although all these orbitals are very different in shape, each can hold a maximum of two electrons.

Electrons usually occupy the lowest energy levels available in an atom. And within each energy level, electrons occupy orbitals with the lowest energy. In any energy level, an *s* orbital has the lowest energy. A *p* orbital has slightly more energy, followed by a *d* orbital. An *f* orbital has the greatest energy.

orbital a region in an atom where there is a high probability of finding electrons

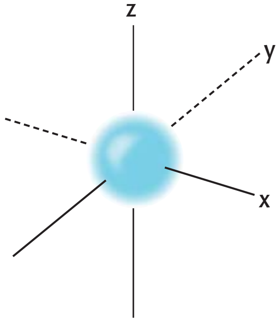

Figure 3-6
An *s* orbital is shaped like a sphere, so it has only one possible orientation in space. An *s* orbital can hold a maximum of two electrons.

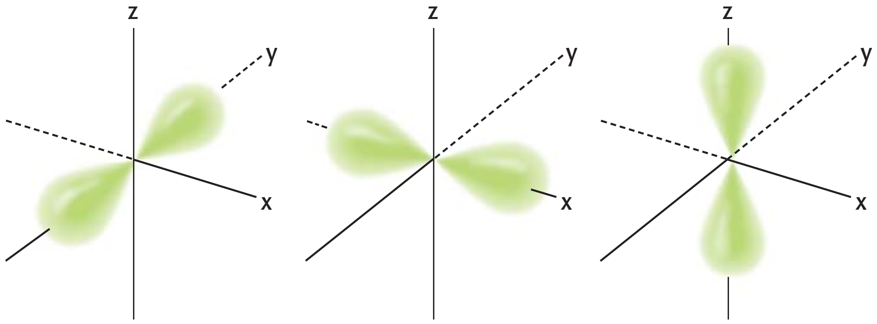

Figure 3-7
Each of these *p* orbitals can hold a maximum of two electrons, so all three together can hold a total of six electrons.

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Every atom has one or more valence electrons

valence electron an electron in the outermost energy level of an atom

An electron in the outermost energy level of an atom is called a **valence electron.** The single electron of a hydrogen atom is a valence electron because it is the only electron the atom has. The glowing red sign shown in **Figure 3-8** is made of neon atoms. In a neon atom, two electrons fill the lowest energy level. Its valence electrons, then, are the eight electrons that are farther away from the nucleus in the atom's second (and outermost) energy level.

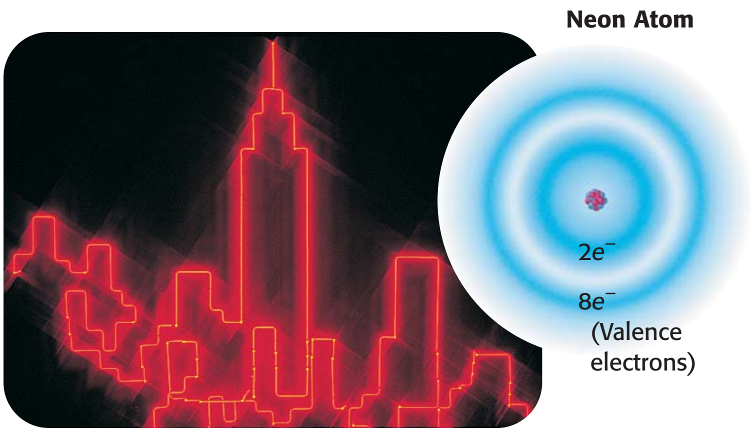

Figure 3-8
The neon atoms of this sign have eight valence electrons. The sign lights up because atoms first gain energy and then release this energy in the form of light.

SECTION 3.1 REVIEW

SUMMARY

- Elements are made of very small units called atoms.
- The nucleus of an atom is made of positively charged protons and uncharged neutrons.
- Surrounding the nucleus are tiny negatively charged electrons.
- Atoms have an equal number of protons and electrons.
- In Bohr's model of the atom, electrons orbit the nucleus in set paths much like the planets orbit the sun in our solar system.
- In the modern atomic model, electrons are found in orbitals within each energy level.
- Electrons in the outermost energy level are called valence electrons.

CHECK YOUR UNDERSTANDING

1. **Summarize** the main ideas of Dalton's atomic theory.
2. **Explain** why Dalton's theory was more successful than Democritus's theory.
3. **List** the charge, mass, and location of each of the three subatomic particles found within atoms.
4. **Predict** how many valence electrons a nitrogen atom has. (Nitrogen has a total of seven electrons, two of which fill the lowest energy level.)
5. **Explain** why oxygen atoms are neutral. (Oxygen has eight positively charged protons.)
6. **Compare** an atom's structure to a ladder. What parts of the ladder correspond to the energy levels of the atom? Identify one way a real ladder is not a good model for the atom.
7. **Explain** how the path of an electron differs in Bohr's model and in the modern model of the atom.
8. **Critical Thinking** In the early 1900s, two associates of New Zealander Ernest Rutherford bombarded thin sheets of gold with positively charged subatomic particles. They found that most of the particles passed right through the sheets but some bounced back as if they had hit something solid. Based on their results, what do you think the majority of an atom is made of? What part of the atom caused the particles to bounce back? (**Hint:** Positive charges repel other positive charges.)

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3.2

A Guided Tour of the Periodic Table

OBJECTIVES

- Relate the organization of the periodic table to the arrangement of electrons within an atom.
- Explain why some atoms gain or lose electrons to form ions.
- Determine how many protons, neutrons, and electrons an isotope has, given its symbol, atomic number, and mass number.
- Describe how the abundance of isotopes affects an element's average atomic mass.

KEY TERMS

periodic law
period
group
ionization
ion
cation
anion
atomic number
mass number
isotopes
atomic mass unit (amu)
average atomic mass

When you are in a store, chances are you know where to look for your favorite items because they are not placed randomly on the shelves. Similar items are usually grouped together, as shown in **Figure 3-9,** so that you can find what you need quickly. The periodic table organizes all the elements in a similar way.

Organization of the Periodic Table

The periodic table groups similar elements together. This organization makes it easier to predict the properties of an element based on where it is in the periodic table. In the periodic table shown in **Figure 3-10,** on the following pages, elements are represented by their symbols. The elements are also arranged in a certain order. The order is based on the number of protons an atom of that element has in its nucleus.

A hydrogen atom has one proton, so hydrogen is the first element listed in the periodic table. A helium atom has two protons and is the second element listed, and so on. Elements are listed in this order in the periodic table because the **periodic law** states that when elements are arranged this way, similarities in their properties will occur in a regular pattern.

periodic law properties of elements tend to change in a regular pattern when elements are arranged in order of increasing atomic number, or number of protons in their atoms

Figure 3-9
In many stores, similar items are grouped so that they are easier to find.

Figure 3-10

The Periodic Table of the Elements

Key:

6	Atomic number
C	Symbol
Carbon	Name
12.011	Average atomic mass

Period	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
1	1 **H** Hydrogen 1.007 94								
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012 182							
3	11 **Na** Sodium 22.989 768	12 **Mg** Magnesium 24.3050							
4	19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955 910	22 **Ti** Titanium 47.88	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938 05	26 **Fe** Iron 55.847	27 **Co** Cobalt 58.933 20
5	37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.905 85	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906 38	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (97.9072)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906
6	55 **Cs** Cesium 132.905 43	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22
7	87 **Fr** Francium (223.0197)	88 **Ra** Radium (226.0254)	89 **Ac** Actinium (227.0278)	104 **Rf** Rutherfordium (261.11)	105 **Db** Dubnium (262.114)	106 **Sg** Seaborgium (263.118)	107 **Bh** Bohrium (262.12)	108 **Hs** Hassium (265)†	109 **Mt** Meitnerium (266)†

58 **Ce** Cerium 140.115	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (144.9127)	62 **Sm** Samarium 150.36
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.035 88	92 **U** Uranium 238.0289	93 **Np** Neptunium (237.0482)	94 **Pu** Plutonium 244.0642

† Estimated from currently available IUPAC data.

* The systematic names and symbols for elements greater than 109 will be used until the approval of trivial names by IUPAC.

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Metals
- Alkali metals
- Alkaline-earth metals
- Transition metals
- Other metals

Nonmetals
- Hydrogen
- Semiconductors
- Halogens
- Noble gases
- Other nonmetals

Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
								2 **He** Helium 4.002 602
			5 **B** Boron 10.811	6 **C** Carbon 12.011	7 **N** Nitrogen 14.006 74	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.998 4032	10 **Ne** Neon 20.1797
			13 **Al** Aluminum 26.981 539	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.9738	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.921 59	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.757	52 **Te** Tellurium 127.60	53 **I** Iodine 126.904	54 **Xe** Xenon 131.29
78 **Pt** Platinum 195.08	79 **Au** Gold 196.966 54	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.980 37	84 **Po** Polonium (208.9824)	85 **At** Astatine (209.9871)	86 **Rn** Radon (222.0176)
110 **Uun*** Ununnilium (269)†	111 **Uuu*** Unununium (272)†	112 **Uub*** Ununbium (277)†		114 **Uuq*** Ununquadium (285)†		116 **Uuh*** Ununhexium (289)†		118 **Uuo*** Ununoctium (293)†

63 **Eu** Europium 151.966	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.925 34	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.930	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.934 21	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
95 **Am** Americium (243.0614)	96 **Cm** Curium (247.0703)	97 **Bk** Berkelium (247.0703)	98 **Cf** Californium (251.0796)	99 **Es** Einsteinium (252.083)	100 **Fm** Fermium (257.0951)	101 **Md** Mendelevium (258.10)	102 **No** Nobelium (259.1009)	103 **Lr** Lawrencium (262.11)

The atomic masses listed in this table reflect the precision of current measurements. (Values listed in parentheses are those of the element's most stable or most common isotope.) In calculations throughout the text, however, atomic masses have been rounded to two places to the right of the decimal.

Using the periodic table to determine electronic arrangement

period a horizontal row of elements in the periodic table

Horizontal rows in the periodic table are called **periods.** Just as the number of protons an atom has increases by one as you move from left to right across a period, so does its number of electrons. You can determine how an atom's electrons are arranged if you know where the corresponding element is located in the periodic table.

Hydrogen and helium are both located in Period 1 of the periodic table. **Figure 3-11** shows that a hydrogen atom has one electron in an *s* orbital, while a helium atom has one more electron, for a total of two. Lithium is located in Period 2. A lithium atom is just like a helium atom, except that it has a third electron in an *s* orbital in the second energy level, as follows:

Energy level	Orbital	Number of electrons
1	*s*	2
2	*s*	1

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As you continue to move to the right in Period 2, you can see that a carbon atom has electrons in *p* orbitals and *s* orbitals. The locations of the six electrons in a carbon atom are as follows:

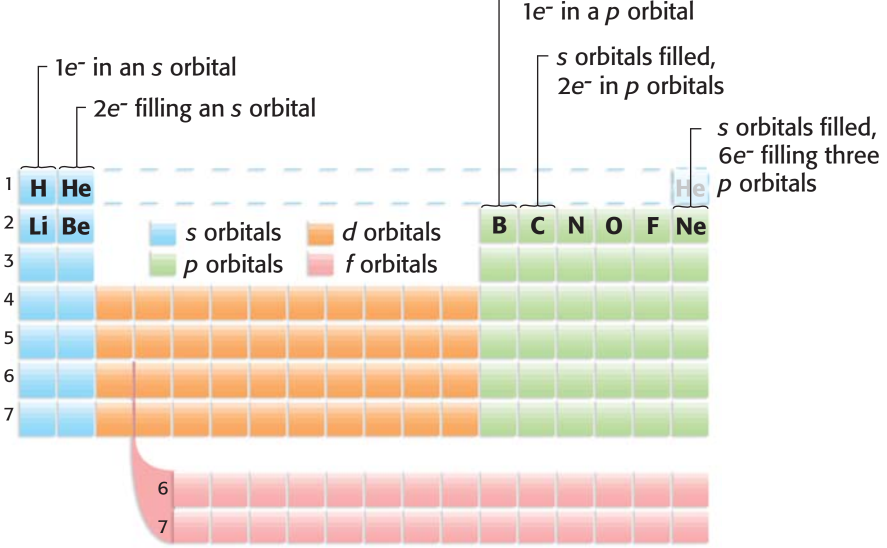
Energy level	Orbital	Number of electrons
1	*s*	2
2	*s*	2
2	*p*	2

group (family) a vertical column of elements in the periodic table

A nitrogen atom has three electrons in *p* orbitals, an oxygen atom has four, and a fluorine atom has five. **Figure 3-11** shows that a neon atom has six electrons in *p* orbitals. Each orbital can hold two electrons, so all three *p* orbitals are filled.

Figure 3-11
The electronic arrangement of atoms becomes increasingly more complex as you move further right across a period and further down a group of the periodic table.

Electron Locations



Elements in the same group have similar properties

Valence electrons determine the chemical properties of atoms. Atoms of elements in the same **group,** or column, have the same number of valence electrons, so these elements have similar properties. Remember that these elements are not exactly alike, though, because atoms of these elements have different numbers of protons in their nuclei and different numbers of electrons in their filled inner energy levels.

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Some Atoms Form Ions

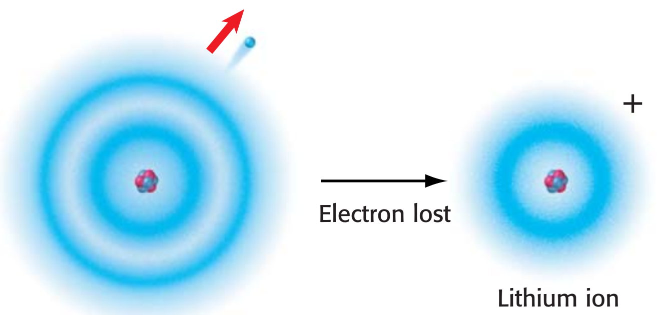


Figure 3-12
The valence electron of a reactive lithium atom may be removed to form a lithium ion, Li^+, with a 1+ charge.

Atoms of Group 1 elements are reactive because their outermost energy levels are only partially filled. Atoms that do not have filled outermost energy levels may undergo a process called **ionization.** That is, they may gain or lose valence electrons so that they have a full outermost energy level. If an atom gains or loses electrons, it no longer has the same number of electrons as it does protons. Because the charges do not cancel completely as they did before, the **ion** that forms has a net electric charge, as shown for the lithium ion in **Figure 3-12.**

A lithium atom loses one electron to form a 1+ charged ion

Lithium is located in Group 1 of the periodic table. It is so reactive that it even reacts with air. An electron is easily removed from a lithium atom, as shown in **Figure 3-12.** The model for the atomic structure of lithium explains its reactivity. A lithium atom has three electrons. Two of these electrons occupy the first energy level, but only one electron occupies the second energy level. This single valence electron makes lithium very reactive. Removing this electron forms a positive ion, or **cation.**

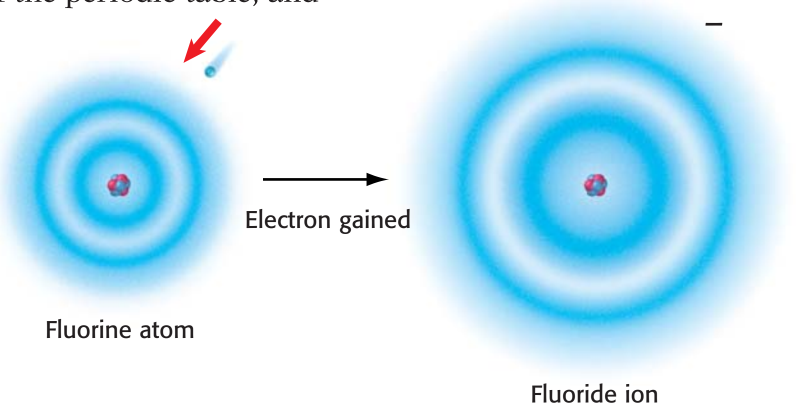
A lithium ion, written as Li^+, is much less reactive than a lithium atom because it has a full outermost energy level. Atoms of other Group 1 elements also have one valence electron. They are also reactive and behave similarly to lithium. You will learn more about Group 1 elements in Section 3.3.

- **ionization** the process of adding electrons to or removing electrons from an atom or group of atoms
- **ion** an atom or group of atoms that has lost or gained one or more electrons and therefore has a net electric charge
- **cation** an ion with a positive charge
- **anion** an ion with a negative charge

A fluorine atom gains one electron to form a 1– charged ion

Like lithium, fluorine is also very reactive. However, instead of losing an electron to become less reactive, an atom of the element fluorine gains one electron to form an ion with a 1– charge. Fluorine is located in Group 17 of the periodic table, and each atom has nine electrons. Two of these electrons occupy the first energy level, and seven valence electrons occupy the second energy level. A fluorine atom needs only one more electron to have a full outermost energy level. An atom of fluorine easily gains this electron to form a negative ion, or **anion,** as shown in **Figure 3-13.**

Figure 3-13
A fluorine atom easily gains one valence electron to form a fluoride ion, F^-, with a 1– charge.



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PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc One, Module 3:
Periodic Properties
Use the Interactive Tutor to learn more about this topic.

Ions of fluorine are called fluoride ions and are written as F^-. Because atoms of other Group 17 elements also have seven valence electrons, they are also reactive and behave similarly to fluorine. You will learn more about Group 17 elements in Section 3.3.

How Do the Structures of Atoms Differ?

As you have seen with lithium and fluorine, atoms of different elements have their own unique structures. Because these atoms have different structures, they have different properties. An atom of hydrogen found in a molecule of swimming-pool water has properties very different from an atom of uranium in nuclear fuel.

Atomic number equals the number of protons

atomic number the number of protons in the nucleus of an atom

The **atomic number,** *Z,* tells you how many protons are in an atom. Remember that atoms are always neutral because they have an equal number of protons and electrons. Therefore, the atomic number also equals the number of electrons the atom has. Each element has a different atomic number. For example, the simplest atom, hydrogen, has just one proton and one electron, so for hydrogen, $Z = 1$. The largest naturally occurring atom, uranium, has 92 protons and 92 electrons, so $Z = 92$ for uranium. The atomic number for a given element never changes.

Mass number equals the total number of subatomic particles in the nucleus

mass number the total number of protons and neutrons in the nucleus of an atom

The **mass number,** *A,* of an atom equals the number of protons plus the number of neutrons. A fluorine atom has 9 protons and 10 neutrons, so $A = 19$ for fluorine. This mass number includes only the number of protons and neutrons (and not electrons) because protons and neutrons provide most of the atom's mass. Although atoms of an element always have the same atomic number, they can have different mass numbers. **Figure 3-14** shows which subatomic particles in the nucleus of an atom contribute to the atomic number and which contribute to the mass number.

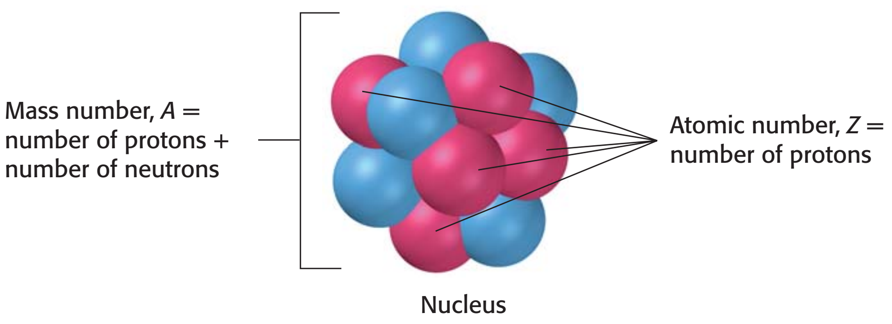


Figure 3-14
Atoms of the same element have the same number of protons and therefore have the same atomic number. But they may have different mass numbers, depending on how many neutrons each atom has.

Isotopes of Hydrogen

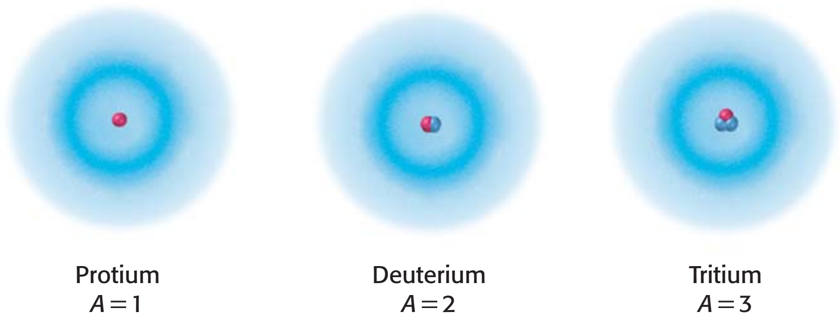


Figure 3-15
Protium has only a proton in its nucleus. Deuterium has both a proton and a neutron in its nucleus, while tritium has a proton and two neutrons.

Isotopes of an element have different numbers of neutrons

Neutrons can be added to an atom without affecting the number of protons and electrons the atom is made of. Many elements have only one stable form, while other elements have different "versions" of their atoms. Each version has the same number of protons and electrons as all other versions but a different number of neutrons. These different versions, or **isotopes,** vary in mass but are all atoms of the same element because they each have the same number of protons.

isotopes any atoms having the same number of protons but different numbers of neutrons

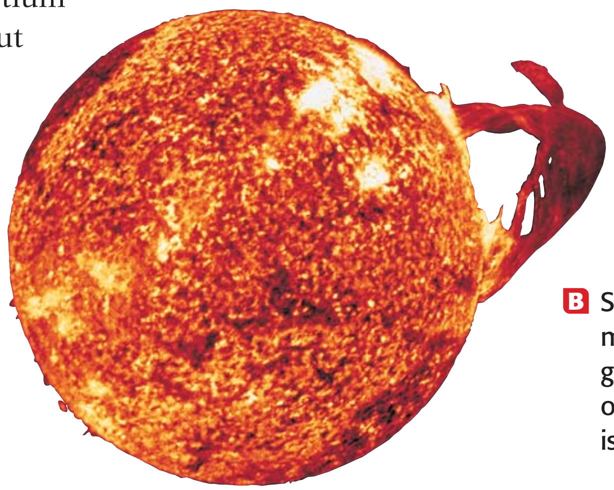
The three isotopes of hydrogen, shown in **Figure 3-15,** all share similar chemical properties because each is made of one proton and one electron. The most common hydrogen isotope, protium, has only a proton in its nucleus. A second isotope of hydrogen has a proton and a neutron. The mass number, *A,* of this second isotope is two, and the isotope is twice as massive. In fact, this isotope is sometimes called "heavy hydrogen." It is also known as deuterium, or hydrogen-2. A third isotope has a proton and two neutrons in its nucleus. This third isotope, tritium, has a mass number of three.

Some isotopes are more common than others

Hydrogen is present on both the sun and on Earth. In both places, protium (the hydrogen isotope without neutrons in its nucleus) is found most often. Only a very small fraction of the less common isotope of hydrogen, deuterium, is found on the sun and on Earth, as shown in **Figure 3-16.** Tritium is an unstable isotope that decays over time, so it is found least often.

Figure 3-16

A Hydrogen makes up less than 1 percent of Earth's crust. Only 1 out of every 6000 of these hydrogen atoms is a deuterium isotope.



B Seventy-five percent of the mass of the sun is hydrogen, with protium isotopes outnumbering deuterium isotopes 50 000 to 1.

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Figure 3-17
One isotope of chlorine has 18 neutrons, while the other isotope has 20 neutrons.

Mass number
$^{35}_{17}Cl$
Atomic number
17 protons
17 electrons
35 – 17 = **18 neutrons**

Mass number
$^{37}_{17}Cl$
Atomic number
17 protons
17 electrons
37 – 17 = **20 neutrons**

Quick ACTIVITY

Isotopes
Calculate the number of neutrons there are in the following isotopes. (Use the periodic table to find the atomic numbers.)

1. carbon-14
2. nitrogen-15
3. sulfur-35
4. calcium-45
5. iodine-131

Calculating the number of neutrons in an atom

Atomic numbers and mass numbers may be included along with the symbol of an element to represent different isotopes. The two isotopes of chlorine are represented this way in **Figure 3-17.** If you know the atomic number and mass number of an atom, you can calculate the number of neutrons it has.

Uranium has several isotopes. The isotope that is used in nuclear reactors is uranium-235, or $^{235}_{92}U$. Like all uranium atoms, it has an atomic number of 92, so it must have 92 protons and 92 electrons. It has a mass number of 235, which means its number of protons and neutrons together is 235. The number of neutrons must be 143.

Mass number (*A*):	235
Atomic number (*Z*):	– 92
Number of neutrons:	143

The mass of an atom

The mass of a single atom is very small. A single fluorine atom has a mass less than one trillionth of a billionth of a gram. Because it is very hard to work with such tiny masses, atomic masses are usually expressed in atomic mass units. An **atomic mass unit (amu)** is equal to one-twelfth of the mass of a carbon-12 atom. This isotope of carbon has six protons and six neutrons, so individual protons and neutrons must each have a mass of about 1.0 amu because electrons contribute very little mass.

atomic mass unit (amu) a quantity equal to one-twelfth of the mass of a carbon-12 atom

Often, the atomic mass listed for an element in the periodic table is an **average atomic mass** for the element as it is found in nature. The average atomic mass for an element is a weighted average, so the more commonly found isotopes have a greater effect on the average than rare isotopes.

average atomic mass the weighted average of the masses of all naturally occurring isotopes of an element

Figure 3-18 shows how the natural abundance of chlorine's two isotopes affects chlorine's average atomic mass. The average atomic mass of chlorine is 35.45 amu. This mass is much closer to 35 amu than to 37 amu. That's because the atoms of chlorine with masses of nearly 35 amu are found more often and therefore contribute more to chlorine's average atomic mass than chlorine atoms with masses of nearly 37 amu.

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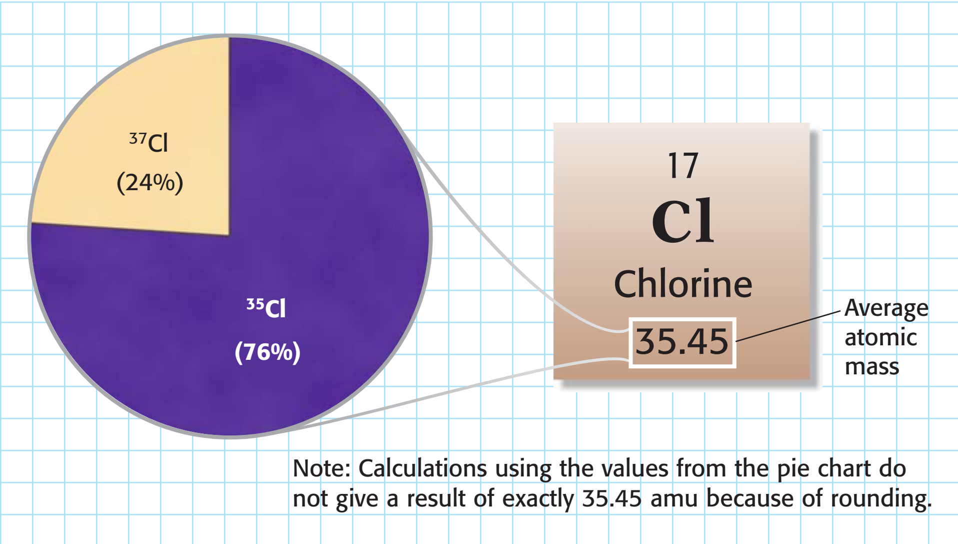

Figure 3-18
The average atomic mass of chlorine is closer to 35 amu than it is to 37 amu because ^{35}Cl isotopes are found more often than ^{37}Cl isotopes.

SECTION 3.2 REVIEW

SUMMARY

- Elements are arranged in order of increasing atomic number so that elements with similar properties are in the same column, or group.
- Elements in the same group have the same number of valence electrons.
- Reactive atoms may gain or lose valence electrons to form ions.
- An atom's atomic number is its number of protons.
- An atom's mass number is its total number of subatomic particles in the nucleus.
- Isotopes of an element have different numbers of neutrons, and therefore have different masses.
- An element's average atomic mass is a weighted average of the masses of its naturally occurring isotopes.

CHECK YOUR UNDERSTANDING

1. **Explain** how you can determine the number of neutrons an atom has from an atom's mass number and its atomic number.
2. **Calculate** how many neutrons a phosphorus-32 atom has.
3. **Name** the elements represented by the following symbols:
   a. Li **d.** Br **g.** Na
   b. Mg **e.** He **h.** Fe
   c. Cu **f.** S **i.** K
4. **Compare** the number of valence electrons an oxygen, O, atom has with the number of valence electrons a selenium, Se, atom has. Are oxygen and selenium in the same period or group?
5. **Describe** how a sodium ion differs from a sodium atom. (**Hint:** The behavior of sodium is similar to that of lithium.) Which form of sodium is more likely to be found in nature? Explain your reasoning.
6. **Predict** which isotope of nitrogen is more commonly found, nitrogen-14 or nitrogen-15. (**Hint:** What is the average atomic mass listed for nitrogen in the periodic table?)
7. **Describe** why the elements in the periodic table are arranged in order of increasing atomic number.
8. **Critical Thinking** Before 1937, all naturally occurring elements had been discovered, but no one had found any trace of element 43. Chemists were still able to predict the chemical properties of this element (now called technetium), which is widely used today for diagnosing medical problems. How were these predictions possible? Which elements would you expect to be similar to technetium?

3.3

Families of Elements

KEY TERMS
- metals
- nonmetals
- semiconductors
- alkali metals
- alkaline-earth metals
- transition metals
- halogens
- noble gases

OBJECTIVES
- Locate alkali metals, alkaline-earth metals, and transition metals in the periodic table.
- Locate semiconductors, halogens, and noble gases in the periodic table.
- Relate an element's chemical properties to the electron arrangement of its atoms.

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TOPIC: Element families
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KEYWORD: HK1035

You may have wondered why groups in the periodic table are sometimes called families. Consider your own family. Though each member is unique, you all share certain similarities. All members of the family shown in **Figure 3-19A,** for example, have a similar appearance. Members of a family in the periodic table have many chemical and physical properties in common because they have the same number of valence electrons.

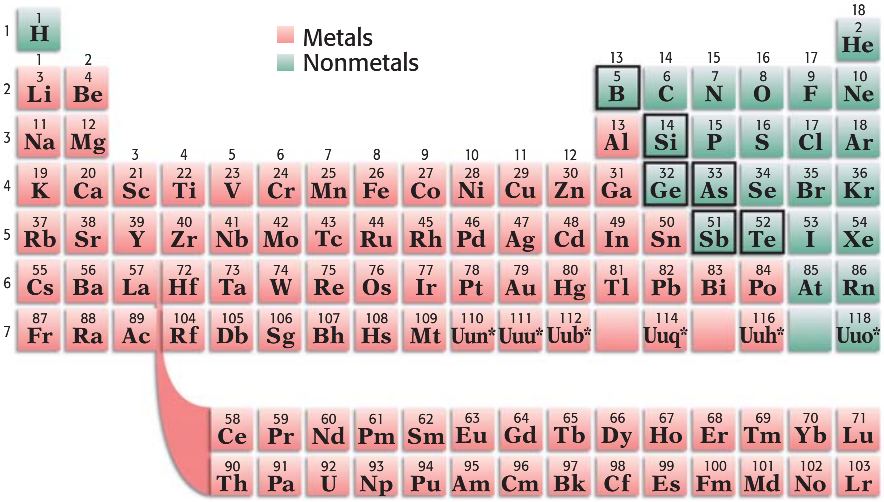
How Are Elements Classified?

Think of each element as a member of a family that is also related to other elements nearby. Elements are classified as metals or nonmetals, as shown in **Figure 3-19B.** This classification groups elements that have similar physical and chemical properties. You will learn more about the chemical properties of elements in Chapter 5.

Figure 3-19
(A) Just like the members of this family, (B) elements in the periodic table share certain similarities.

A

B



Note: Sometimes the boxed elements toward the right side of the periodic table are classified as a separate group and called semiconductors or metalloids.

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As you can see in **Figure 3-19B,** most elements are **metals.** Most metals are shiny solids that can be stretched and shaped. They are also good conductors of heat and electricity. All **nonmetals,** except for hydrogen, are found on the right side of the periodic table. Nonmetals may be solids, liquids, or gases. Solid nonmetals are typically dull and brittle and are poor conductors of heat and electricity. But some elements that are classified as nonmetals can conduct under certain conditions. These elements are sometimes considered to be their own group and are called **semiconductors** or metalloids.

Alkali Metals

Figure 3-20

A The alkali metals are located on the left edge of the periodic table.

Group 1

Atomic number	Symbol	Name	Atomic mass
3	Li	Lithium	6.941
11	Na	Sodium	22.989 768
19	K	Potassium	39.0983
37	Rb	Rubidium	85.4678
55	Cs	Cesium	132.905 43
87	Fr	Francium	(223.0197)

B The alkali metal sodium must be stored in oil. Otherwise, it will react violently with moisture and oxygen in the air.

Metals

Many elements are classified as metals. To further classify metals, similar metals are grouped together. There are four different kinds of metals. Two groups of metals are located on the left side of the periodic table. Other metals, like aluminum, tin, and lead, are located toward the right side of the periodic table. Most metals, though, are located in the middle of the periodic table.

The alkali metal sodium is very reactive

Sodium is found in Group 1 of the periodic table, as shown in **Figure 3-20A.** Like other **alkali metals,** it is soft and shiny and reacts violently with water. For this reason, it must be stored in oil, as shown in **Figure 3-20B,** to prevent it from reacting with moisture in the air.

An atom of an alkali metal is very reactive because it has one valence electron that can easily be removed to form a positive ion. You have already seen in Section 3.2 how lithium, another alkali metal, forms positive ions with a 1+ charge. Similarly, the valence electron of a sodium atom can be removed to form the positive sodium ion Na^+.

Because alkali metals such as sodium are so reactive, they are not found in nature as elements. Instead, they combine with other elements to form compounds. For example, the salt you use to season your food is actually the compound sodium chloride, NaCl. Potassium is another common alkali metal.

- **metals** the elements that are good conductors of heat and electricity
- **nonmetals** the elements that are usually poor conductors of heat and electricity
- **semiconductors** the elements that are intermediate conductors of heat and electricity
- **alkali metals** the highly reactive metallic elements located in Group 1 of the periodic table

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Alkaline-earth Metals

Figure 3-21

A The alkaline-earth metals make up the second column of elements from the left edge of the periodic table.

Group 2

4	**Be**	Beryllium	9.012 182
12	**Mg**	Magnesium	24.3050
20	**Ca**	Calcium	40.078
38	**Sr**	Strontium	87.62
56	**Ba**	Barium	137.327
88	**Ra**	Radium	(226.0254)

B Fish can escape their predators by hiding among the hard projections of limestone coral reefs that are made of calcium compounds.

alkaline-earth metals the reactive metallic elements located in Group 2 of the periodic table

Compounds of the alkaline-earth metal calcium are found in limestone and marble

Calcium is in Group 2 of the periodic table, as shown in **Figure 3-21A,** and is an **alkaline-earth metal.** Atoms of alkaline-earth metals, such as calcium, have two valence electrons. Alkaline-earth metals are less reactive than alkali metals, but they may still react to form positive ions with a 2+ charge. When the valence electrons of a calcium atom are removed, a calcium ion, Ca^{2+}, forms. Alkaline-earth metals like calcium also combine with other elements to form compounds.

Calcium compounds make up the hard shells of many sea animals. When the animals die, their shells settle to form large deposits that eventually become limestone or marble, both of which are very strong materials used in construction. Coral is one example of a limestone structure. The “skeletons” of millions of tiny animals combine to form sturdy coral reefs that many fish rely on for protection, as shown in **Figure 3-21B.** Your bones and teeth also get their strength from calcium compounds.

Magnesium is another alkaline-earth metal that has properties similar to calcium. Magnesium is the lightest of all structural metals and is used to build some airplanes. Magnesium, as Mg^{2+}, activates many of the enzymes that speed up processes in the human body. Magnesium also combines with other elements to form many useful compounds. Two magnesium compounds are commonly used medicines—milk of magnesia and Epsom salt.

Quick ACTIVITY

Elements in Your Food

1. For 1 day, make a list of the ingredients in all the foods and drinks you consume.
2. Identify which ingredients on your list are compounds.
3. For each compound on your list, try to figure out what elements it is made of.

Transition Metals

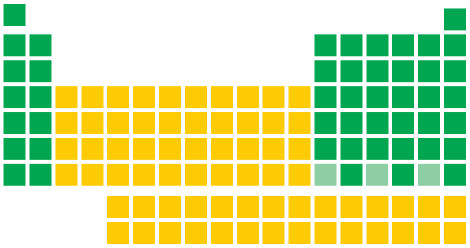

Figure 3-22

A The transition metals are located in the middle of the periodic table.

B The transition metals gold, silver, and platinum are often shaped to make jewelry.

The transition metal gold is mined

Gold is a valuable **transition metal.** **Figure 3-22A** shows that the transition metals are located in Groups 3–12 of the periodic table. Unlike most other transition metals, gold is not found combined with other elements as an ore but as the free metal.

Transition metals, like gold, are much less reactive than sodium or calcium, but they can lose electrons to form positive ions too. There are two possible cations that a gold atom can form. If an atom of gold loses only one electron, it forms Au^{+}. If the atom loses three electrons, it forms Au^{3+}. Some transition metals can form as many as four differently charged cations because of their complex arrangement of electrons.

All metals, including transition metals, conduct heat and electricity. Most metals can also be stretched and shaped into flat sheets, or pulled into wire. Because gold, silver, and platinum are the shiniest metals, they are often molded into different kinds of jewelry, as shown in **Figure 3-22B.**

There are many other useful transition metals. Copper is often used for electrical wiring or plumbing. Light bulb filaments are made of tungsten. Iron, cobalt, copper, and manganese play vital roles in your body chemistry. Mercury, shown in **Figure 3-23,** is the only metal that is a liquid at room temperature. It is often used in thermometers because it flows quickly and easily without sticking to glass.

transition metals the metallic elements located in Groups 3–12 of the periodic table

VOCABULARY ***Skills Tip***

The properties of transition metals *gradually transition, or shift, from being more similar to Group 2 elements to being more similar to Group 13 elements as you move from left to right across a period.*

Figure 3-23

Mercury is an unusual metal because it is a liquid at room temperature. Continued exposure to this volatile metal can harm you because if you breathe in the vapor, it accumulates in your body.

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Inquiry Lab

Why do some metals cost more than others?

Procedure

1. The table at right gives the abundance of some metals in Earth's crust. List the metals in order from most to least abundant.

2. List the metals in order of price, from the cheapest to the most expensive.

Analysis

3. If the price of a metal depends on its abundance, you would expect the order to be the same on both lists. How well do the two lists match? Mention any exceptions.

4. The order of reactivity of these metals, from most reactive to least reactive, is aluminum, zinc, chromium, iron, tin, copper, silver, and gold. Use this information to explain any exceptions you noticed in item 3.

5. Create a spreadsheet that can be used to calculate how many grams of each metal you could buy with $100. COMPUTER SKILL

Metal	Abundance in Earth's crust (%)	Price ($/kg)
Aluminum (Al)	8.2	1.55
Chromium (Cr)	0.01	0.06
Copper (Cu)	0.0060	2.44
Gold (Au)	0.000 0004	11 666.53
Iron (Fe)	5.6	0.03
Silver (Ag)	0.000 007	154.97
Tin (Sn)	0.0002	6.22
Zinc (Zn)	0.007	1.29

Technetium and promethium are synthetic elements

Technetium and promethium are both man-made elements. They are also both *radioactive*, which means the nuclei of their atoms are continually decaying to produce different elements. There are several different isotopes of technetium. The most stable isotope is technetium-99, which has 56 neutrons. Technetium-99 can be used to diagnose cancer as well as other medical problems in soft tissues of the body, as shown in **Figure 3-24.**

When looking at the periodic table, you might have wondered why part of the last two periods of the transition metals are placed toward the bottom. This keeps the periodic table narrow so that similar elements elsewhere in the table still line up. Promethium is one element located in this bottom-most section. Its most useful isotope is promethium-147, which has 86 neutrons. Promethium-147 is an ingredient in some "glow-in-the-dark" paints.

All elements with atomic numbers greater than 92 are also man-made and are similar to technetium and promethium. For example, americium, another element in the bottom-most section of the periodic table, is also radioactive. Tiny amounts of americium-241 are found in most household smoke detectors. Although it may seem scary to have a radioactive element inside your home, so little of the element is present that it does not affect you.

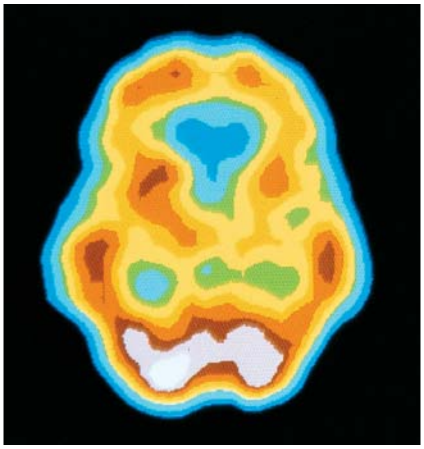

Figure 3-24
With the help of the radioactive isotope technetium-99, doctors are able to confirm that this patient has a healthy brain.

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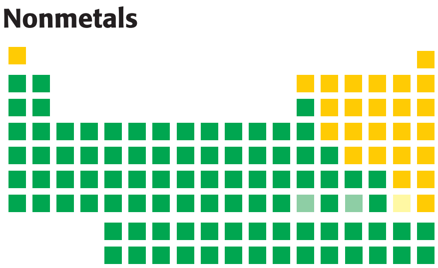
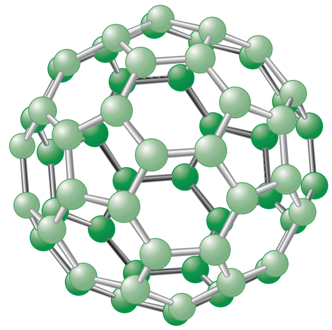


Figure 3-25

A Most nonmetals are located on the right side of the periodic table.



B The way carbon atoms are connected in the most recently discovered form of carbon resembles the familiar pattern of a soccer ball.

Nonmetals

Except for hydrogen, nonmetals are found on the right side of the periodic table. They include some elements in Groups 13–16 and all the elements in Groups 17 and 18.

Carbon is found in three different forms and can also form many compounds

Carbon and other nonmetals are found on the right side of the periodic table, as shown in **Figure 3-25A.** Although carbon in its pure state is usually found as graphite (pencil "lead") or diamond, the existence of fullerenes, a third form, was confirmed in 1990. The most famous fullerene consists of a cluster of 60 carbon atoms, as shown in **Figure 3-25B.**

Carbon can also combine with other elements to form millions of carbon-containing compounds. Carbon compounds are found in both living and nonliving things. Glucose, $C_6H_{12}O_6$, is a sugar in your blood. A type of chlorophyll, $C_{55}H_{72}O_5N_4Mg$, is found in all green plants. Many gasolines contain isooctane, C_8H_{18}, while rubber tires are made of large molecules with many repeating C_5H_8 units.

Nonmetals and their compounds are plentiful on Earth

Oxygen, nitrogen, and sulfur are other common nonmetals. Each may form compounds or gain electrons to form the negative ions oxide, O^{2-}, sulfide, S^{2-}, and nitride, N^{3-}. The most plentiful gases in the air are the nonmetals nitrogen and oxygen. Although sulfur itself is an odorless yellow solid, many sulfur compounds, like those in rotten eggs and skunk spray, are known for their terrible smell.

Connection to ARCHITECTURE

The discoverers of the first and most famous fullerene named the molecule *buckminsterfullerene.* Its structure resembles a geodesic dome, a kind of structure designed by American engineer and inventor R. Buckminster Fuller. A geodesic dome encloses the most space using the fewest materials. Any strains caused by the ground shifting or strong winds have little affect on a geodesic dome. That's because the strains are spread evenly throughout the entire structure. These sturdy structures have been used successfully as radar towers in Antarctica in winds as strong as 90 m/s (200 mi/h) for over 25 years. Geodesic domes provide the framework for some sports arenas, theaters, greenhouses, and even some homes.

Making the Connection

1. How does the shape of a geodesic dome differ from a more typical building?
2. Explain why energy savings are greater in this kind of structure than in a boxlike building that encloses the same amount of space.

Halogens

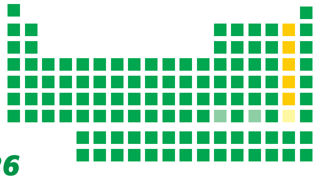


Figure 3-26

A The halogens are in the second column from the right of the periodic table.

Group 17

9	**F**	Fluorine	18.998 4032
17	**Cl**	Chlorine	35.4527
35	**Br**	Bromine	79.904
53	**I**	Iodine	126.904
85	**At**	Astatine	(209.9871)

B Chlorine keeps pool water bacteria-free for swimmers to enjoy.

halogens the highly reactive elements located in Group 17 of the periodic table

Chlorine is a halogen that protects you from harmful bacteria

Chlorine and other **halogens** are located in Group 17 of the periodic table, as shown in **Figure 3-26A.** You have probably noticed the strong smell of chlorine in swimming pools. Chlorine is widely used to kill bacteria in pools, like the one shown in **Figure 3-26B,** as well as in drinking-water supplies.

Like fluorine atoms, which you learned about in Section 3.2, chlorine atoms are very reactive. As a result, chlorine forms compounds. For example, the chlorine in most swimming pools is added in the form of the compound calcium hypochlorite, $Ca(OCl)_2$. Elemental chlorine is a poisonous yellowish green gas made of pairs of joined chlorine atoms. Chlorine gas has the chemical formula Cl_2. A chlorine atom may also gain an electron to form a negative chloride ion, Cl^-. The attractions between Na^+ ions and Cl^- ions form table salt, NaCl.

Fluorine, bromine, and iodine are other Group 17 elements. Fluorine is a poisonous yellowish gas, bromine is a dark red liquid, and iodine is a dark purple solid. Atoms of each of these elements can also form compounds by gaining an electron to become negative ions. A compound containing the negative ion fluoride, F^-, is used in some toothpastes and added to some water supplies to help prevent tooth decay. Adding a compound containing iodine as the negative ion iodide, I^-, to table salt makes "iodized" salt. You need this ion in your diet for your thyroid gland to function properly.

INTEGRATING

EARTH SCIENCE

No fewer than 81 elements have been detected in sea water. Magnesium (mostly as Mg^{2+} ions) and bromine (mostly as Br^- ions) are two such elements. To recover an element from a sample of sea water, you must evaporate some of the water from the sample. When you do this, sodium chloride crystallizes and the liquid that remains becomes more concentrated in bromide, magnesium, and other ions than the original sea water was, making their recovery easier.

The noble gas neon is inert

Neon is one of the **noble gases** that make up Group 18 of the periodic table, as shown in **Figure 3-27A.** It is responsible for the bright reddish orange light of “neon” signs. **Figure 3-27B** shows how mixing neon with another substance, such as mercury, can change the color of a sign.

The noble gases are different from most elements that are gases because they exist as single atoms instead of as molecules. Like other members of Group 18, neon is inert, or unreactive, because its outer energy level is full of electrons. For this reason, neon and other noble gases do not gain or lose electrons to form ions. They also don’t join with other atoms to form compounds under normal conditions.

Helium and argon are other common noble gases. Helium is less dense than air and is used to give lift to airships and balloons. Argon is used to fill light bulbs because its lack of reactivity prevents filaments from burning.

Noble Gases

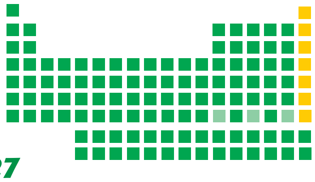


Figure 3-27

A The noble gases are located on the right edge of the periodic table.

B A neon sign is usually reddish orange, but adding a few drops of mercury makes the light a bright blue.

noble gases the unreactive gaseous elements located in Group 18 of the periodic table

Semiconductors are intermediate conductors of heat and electricity

Figure 3-28 shows that the elements sometimes referred to as semiconductors or metalloids are clustered toward the right side of the periodic table. Only six elements—boron, silicon, germanium, arsenic, antimony, and tellurium—are semiconductors. Although these elements are classified as nonmetals, each one also has some properties of metals. And as their name implies, semiconductors are able to conduct heat and electricity under certain conditions.

Boron is an extremely hard element. It is often added to steel to increase steel’s hardness and strength at high temperatures. Compounds of boron are often used to make heat-resistant glass. Arsenic is a shiny solid that tarnishes when exposed to air. Antimony is a bluish white, brittle solid that also shines like a metal. Some compounds of antimony are used as fire retardants. Tellurium is a silvery white solid whose ability to conduct increases slightly with exposure to light.

Semiconductors

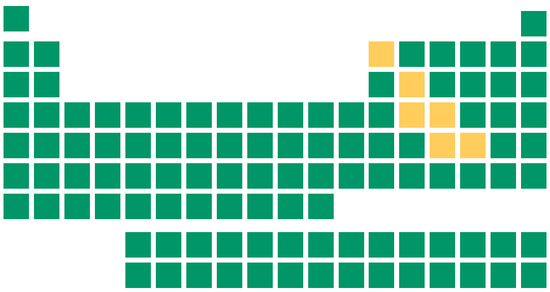


Figure 3-28

Semiconductors are located toward the right side of the periodic table.

Back

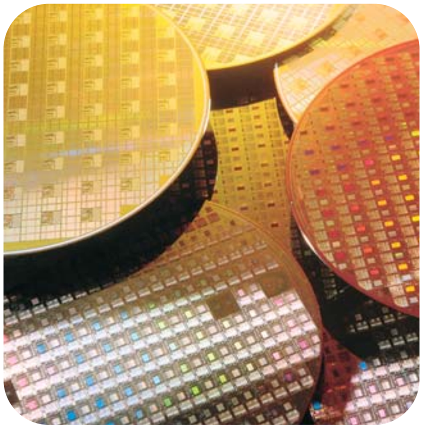


Figure 3-29
Silicon wafers are the basic building blocks of computer chips.

Silicon is the most familiar semiconductor

Silicon atoms, usually in the form of compounds, account for 28 percent of the mass of Earth's crust. Sand is made of the most common silicon compound, called silicon dioxide, SiO_2. Small chips made of silicon, like those shown in **Figure 3-29,** are used in the internal parts of computers.

Silicon is also an important component of other semiconductor devices such as transistors, LED display screens, and solar cells. Impurities such as boron, aluminum, phosphorus, and arsenic are added to the silicon to increase its ability to conduct electricity. These impurities are usually added only to the surface of the chip. This process can be used to make chips of different conductive abilities. This wide range of possible semiconductor devices has led to great advances in electronic technology.

SECTION 3.3 REVIEW

SUMMARY

- Metals are shiny solids that conduct heat and electricity.
- Alkali metals, located in Group 1 of the periodic table, are very reactive.
- Alkaline-earth metals, located in Group 2, are less reactive than alkali metals.
- Transition metals, located in Groups 3–12, are not very reactive.
- Nonmetals usually do not conduct heat or electricity well.
- Nonmetals include the inert noble gases in Group 18, the reactive halogens in Group 17, and some elements in Groups 13–16.
- Semiconductors are nonmetals that are intermediate conductors of heat and electricity.

CHECK YOUR UNDERSTANDING

1. **Classify** the following elements as alkali, alkaline-earth, or transition metals based on their positions in the periodic table:
   a. iron, Fe **c.** strontium, Sr
   b. potassium, K **d.** platinum, Pt
2. **Predict** whether cesium forms Cs^+ or Cs^{2+} ions.
3. **Describe** why chemists might sometimes store reactive chemicals in argon, Ar. To which family does argon belong?
4. **Determine** whether the following substances are likely to be metals or nonmetals:
   a. a shiny substance used to make flexible bed springs
   b. a yellow powder from underground mines
   c. a gas that does not react
   d. a conducting material used within flexible wires
5. **Describe** why atoms of bromine, Br, are so reactive. To which family does bromine belong?
6. **Predict** the charge of a beryllium ion.
7. **Identify** which element is more reactive: lithium, Li, or barium, Ba.
8. **Creative Thinking** Imagine you are a scientist who has just discovered a new element. You have confirmed that the element is a metal but are unsure whether it is an alkali metal, an alkaline-earth metal, or a transition metal. Write a paragraph describing the additional tests you can do to further classify this metal.

WRITING SKILL

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3.4

Using Moles to Count Atoms

OBJECTIVES

- Explain the relationship between a mole of a substance and Avogadro's constant.
- Find the molar mass of an element by using the periodic table.
- Solve problems converting the amount of an element in moles to its mass in grams, and vice versa.

KEY TERMS

mole
Avogadro's constant
molar mass
conversion factor

Counting objects is one of the very first things children learn to do. Counting is easy when the objects being counted are not too small and there are not too many of them. But can you imagine counting the grains of sand along a stretch of beach or the stars in the night-time sky? Counting these would be very difficult.

Counting Things

When people count out large numbers of small things, they often simplify the job by using counting units. For example, when you order popcorn at a movie theater, the salesperson does not count out the individual popcorn kernels to give you. Instead, you specify the size of container you want, and that determines how much popcorn you get. So the "counting unit" for popcorn is the size of the container: small, medium, or large.

There are many different counting units

The counting units for popcorn are only an approximation and are not exact. Everyone who orders a large popcorn will not get exactly the same number of popcorn kernels. Many other items, however, require more-exact counting units, as shown in **Figure 3-30.** For example, you usually cannot buy just one egg at the grocery store. Eggs are packaged by the dozen. Items that are needed in large quantities are packaged into groups as well. Grocers buy fruit from farmers in bushels, or 32 qt containers. Copy shops buy paper in reams, or 500-sheet bundles.

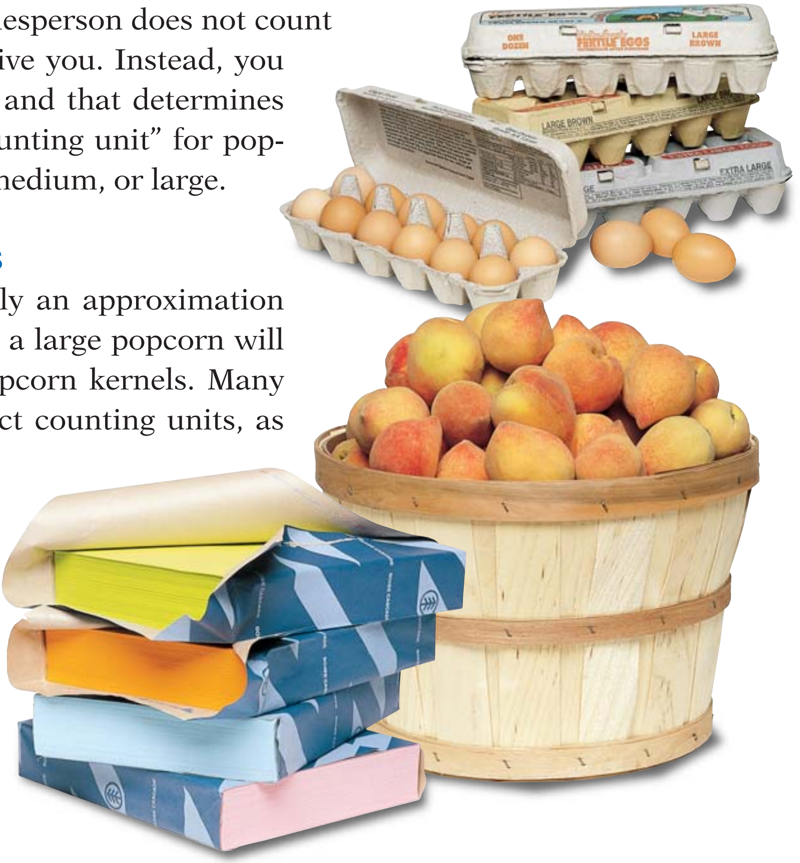

Figure 3-30
Eggs are counted by the dozen, peaches are counted by the bushel, and paper is counted by the ream.

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An object's mass may sometimes be used to "count" it. For example, if a candy shopkeeper knows that 10 gumballs have a mass of 21.4 g, then the shopkeeper can assume that there are 50 gumballs on the scale when the mass is 107 g (21.4 g × 5).

The mole is useful for counting small particles

Because chemists often deal with large numbers of small particles, they use a large counting unit—the **mole,** abbreviated *mol.* A mole is a collection of a very large number of particles.

602 213 670 000 000 000 000 000 to be exact!

This number is usually written as 6.022×10^{23}/mol and is referred to as **Avogadro's constant.** The constant is named in honor of the Italian scientist Amedeo Avogadro. Avogadro's constant is defined as the number of particles, 6.022×10^{23}, in exactly 1 mol of a pure substance.

One mole of gumballs is 6.022×10^{23} gumballs. One mole of popcorn is 6.022×10^{23} kernels of popcorn. This amount of popcorn would not only cover the United States but form a pile about 500 km (310 mi) high! It is highly unlikely that you will ever come in contact with this much gum or popcorn, so it does not make sense to use moles to count either of these items. The mole is very useful, however, for counting tiny atoms.

mole the SI base unit that describes the amount of a substance

Avogadro's constant the number of particles in 1 mol; equals 6.022×10^{23}/mol

molar mass the mass in grams of 1 mol of a substance

Did You Know?

Did you know that Avogadro never knew his own constant? Count Amedeo Avogadro (1776–1856) was a lawyer who became interested in mathematics and physics. Avogadro's constant was actually determined by Joseph Loschmidt, a German physicist in 1865, nine years after Avogadro's death.

Moles and grams are related

The mass in grams of 1 mol of a substance is called its **molar mass.** For example, 1 mol of carbon-12 atoms has a molar mass of 12.00 g. But an entire mole of an element will usually include atoms of several isotopes. So the molar mass of an element in grams is the same as its average atomic mass in amu, which is listed in the periodic table. The average atomic mass listed for carbon in the periodic table is 12.01 amu. One mole of carbon, then, has a mass of 12.01 g. **Figure 3-31** demonstrates this idea for magnesium.

Figure 3-31
One mole of magnesium (6.022×10^{23} Mg atoms) has a mass of 24.30 g. Note that the balance is only accurate to one-tenth of a gram, so it reads 24.3 g.

You might wonder why 6.022×10^{23} represents the number of particles in 1 mol. Experiments have shown that 6.022×10^{23} is the number of carbon-12 atoms in 1 mol of carbon-12. One mole of carbon consists of 6.022×10^{23} carbon atoms, with an average mass of 12.01 amu. So 6.022×10^{23} carbon atoms together have a mass of 12.01 g.

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SCLINKS NSTA

TOPIC: Avogadro's constant
GO TO: www.scilinks.org
KEYWORD: HK1036

Calculating with Moles

Because the amount of a substance and its mass are related, it is often useful to convert moles to grams, and vice versa. You can use **conversion factors** to relate units.

conversion factor a ratio equal to one that expresses the same quantity in two different ways

Using conversion factors

How did the shopkeeper mentioned on page 96 know the mass of 50 gumballs? He multiplied by a conversion factor to determine the number of gumballs on the scale from their combined mass. Multiplying by a conversion factor is like multiplying by 1 because both parts of the conversion factor are always equal.

The shopkeeper knows that exactly 10 gumballs have a combined mass of 21.4 g. This relationship can be written as two equivalent conversion factors, both of which are shown below.

$$\frac{10 \text{ gumballs}}{21.4 \text{ g}} \qquad \frac{21.4 \text{ g}}{10 \text{ gumballs}}$$

The shopkeeper can use one of these conversion factors to determine the mass of 50 gumballs because mass increases in a predictable way as more gumballs are added to the scale, as you can see from **Figure 3-32.**

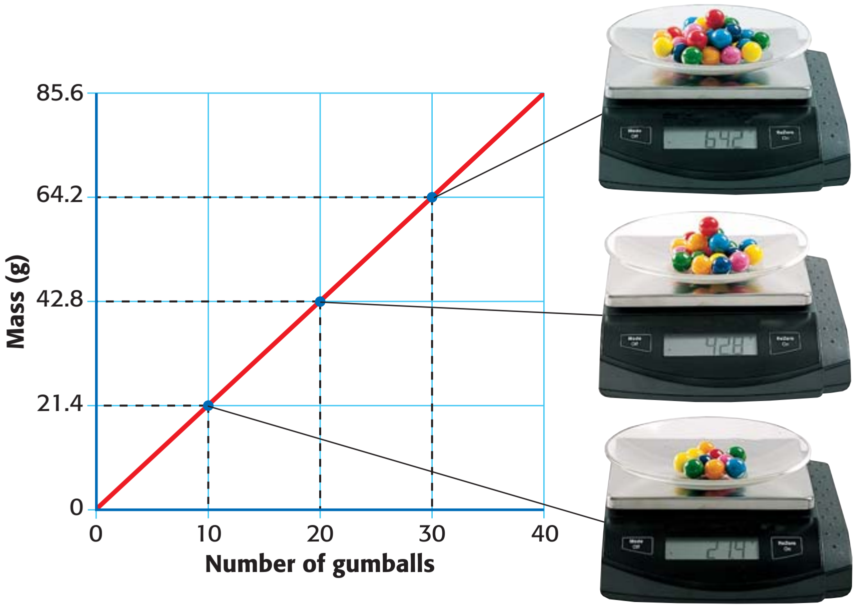

Figure 3-32
There is a direct relationship between the number of gumballs and their mass. Ten gumballs have a mass of 21.4 g, 20 gumballs have a mass of 42.8 g, and 30 gumballs have a mass of 64.2 g.

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Math Skills

Conversion Factors What is the mass of exactly 50 gumballs?

1 **List the given and unknown values.**

Given: mass of 10 gumballs = 21.4 g

Unknown: mass of 50 gumballs = ? g

2 **Write down the conversion factor that converts number of gumballs to mass.**

The conversion factor you choose should have the unit you are solving for (g) in the numerator and the unit you want to cancel (number of gumballs) in the denominator.

$$\frac{21.4 \text{ g}}{10 \text{ gumballs}}$$

3 **Multiply the number of gumballs by this conversion factor, and solve.**

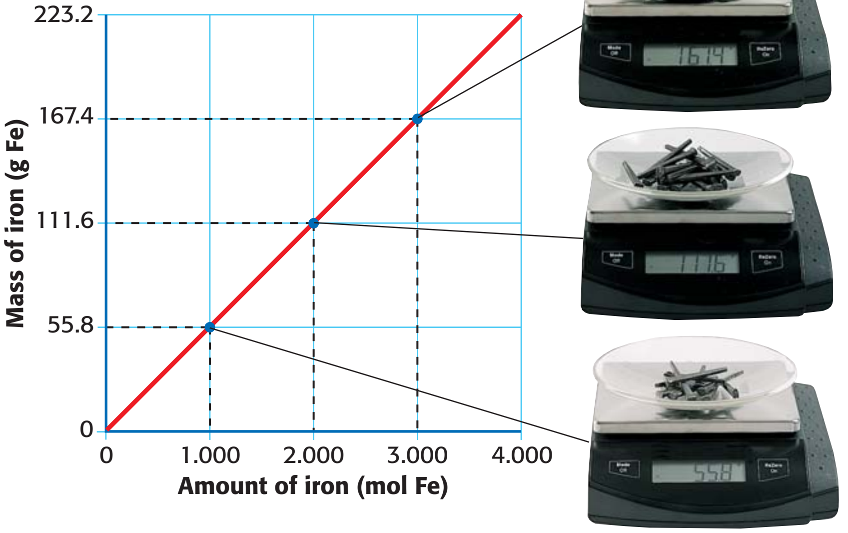
$$50 \cancel{\text{gumballs}} \times \frac{21.4 \text{ g}}{10 \cancel{\text{gumballs}}} = 107 \text{ g}$$

Practice

Conversion Factors

1. What is the mass of exactly 150 gumballs?
2. If you want 50 eggs, how many dozens must you buy? How many extra eggs do you have to take?
3. If a football player is tackled 1.7 ft short of the end zone, how many more yards does the team need to get a touchdown?

Figure 3-33
There is a direct relationship between the amount of an element and its mass.



Relating moles to grams

Just as in the gumball example, there is also a relationship between the amount of an element in moles and its mass in grams. This relationship is graphed for iron nails in **Figure 3-33.** Because the amount of iron and the mass of iron are directly related, the graph is a straight line.

An element's molar mass can be used as if it were a conversion factor. Depending on which conversion factor you use, you can solve for either the amount of the element or its mass.

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Converting between the amount of an element in moles and its mass in grams is outlined in **Figure 3-34.** For example, you can determine the mass of 5.50 mol of iron by using **Figure 3-34** as a guide. First you must find iron in the periodic table. Its average atomic mass is 55.85 amu. This means iron's molar mass is 55.85 g/mol Fe. Now you can set up the problem using the molar mass as if it were a conversion factor, as shown in the sample problem below.

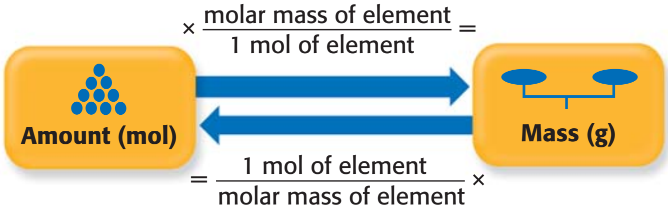

Figure 3-34
The molar mass of an element allows you to convert between the amount of the element and its mass.

Math Skills

Converting Amount to Mass Determine the mass in grams of 5.50 mol of iron.

1 List the given and unknown values.

Given: amount of iron = 5.50 mol Fe
molar mass of iron = 55.85 g/mol Fe
Unknown: mass of iron = ? g Fe

2 Write down the conversion factor that converts moles to grams.

The conversion factor you choose should have what you are trying to find (grams of Fe) in the numerator and what you want to cancel (moles of Fe) in the denominator.

$$\frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}}$$

3 Multiply the amount of iron by this conversion factor, and solve.

$$5.50 \text{ ~~mol Fe~~} \times \frac{55.85 \text{ g Fe}}{1 \text{ ~~mol Fe~~}} = 307 \text{ g Fe}$$

Practice HINT

Notice how iron's molar mass, 55.85 g/mol Fe, includes units (g/mol) and a chemical symbol (Fe). The units specify that this mass applies to 1 mol of substance. The symbol for iron, Fe, clearly indicates the substance. Remember to always include units in your answers and make clear the substance to which these units apply. Otherwise, your answer has no meaning.

Practice

Converting Amount to Mass

What is the mass in grams of each of the following?

1. 2.50 mol of sulfur, S
2. 1.80 mol of calcium, Ca
3. 0.50 mol of carbon, C
4. 3.20 mol of copper, Cu

You can determine the amount of an element from its mass in much the same way, as the next sample problem on the next page shows.

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Math Skills

Converting Mass to Amount Determine the amount of iron present in 352 g of iron.

1 List the given and unknown values.

Given: mass of iron = 352 g Fe
molar mass of iron = 55.85 g/mol Fe

Unknown: amount of iron = ? mol Fe

2 Write down the conversion factor that converts grams to moles.

The conversion factor you choose should have what you are trying to find (moles of Fe) in the numerator and what you want to cancel (grams of Fe) in the denominator.

$$\frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}}$$

3 Multiply the mass of iron by this conversion factor, and solve.

$$352 \cancel{\text{ g Fe}} \times \frac{1 \text{ mol Fe}}{55.85 \cancel{\text{ g Fe}}} = 6.30 \text{ mol Fe}$$

SECTION 3.4 REVIEW

SUMMARY

- One mole of a substance has as many particles as there are atoms in exactly 12 g of carbon-12.
- Avogadro's constant, 6.022×10^{23}/mol, is equal to the number of particles in 1 mol.
- Molar mass is the mass in grams of 1 mol of a substance.
- An element's molar mass in grams is equal to its average atomic mass in amu.
- An element's molar mass can be used to convert from amount to mass, and vice versa.

CHECK YOUR UNDERSTANDING

1. **Define** Avogadro's constant. Describe how Avogadro's constant relates to a mole of a substance.
2. **Determine** the molar mass of the following elements:
   a. manganese, Mn **c.** arsenic, As
   b. cadmium, Cd **d.** strontium, Sr
3. **List** the two equivalent conversion factors for the molar mass of silver, Ag.
4. **Explain** why a graph showing the relationship between the amount of a particular element and the element's mass is a straight line.
5. **Critical Thinking** Which has more atoms: 3.0 g of iron, Fe, or 2.0 g of sulfur, S?

Math Skills

6. What is the mass in grams of 0.48 mol of platinum, Pt?
7. How many moles are present in 620 g of mercury, Hg?
8. How many moles are present in 11 g of silicon, Si?
9. How many moles are present in 205 g of helium, He?

CHAPTER 3 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 76, 85, 94, and 100. The key vocabulary terms are listed on pages 70, 77, 86, and 95.

UNDERSTANDING CONCEPTS

1. Which of Dalton's statements about the atom was later proven false?
   a. Atoms cannot be subdivided.
   b. Atoms are tiny.
   c. Atoms of different elements are not identical.
   d. Atoms join to form molecules.

2. Which statement is not true of Bohr's model of the atom?
   a. The nucleus can be compared to the sun.
   b. Electrons orbit the nucleus.
   c. An electron's path is not known exactly.
   d. Electrons exist in energy levels.

3. According to the modern model of the atom, __________.
   a. moving electrons form an electron cloud
   b. electrons and protons circle neutrons
   c. neutrons have a positive charge
   d. the number of protons an atom has varies

4. If an atom has a mass of 11 amu and contains five electrons, its atomic number must be __________.
   a. 55 **c.** 6
   b. 16 **d.** 5

5. Which statement is true concerning atoms of elements in the same group of the periodic table?
   a. They have the same number of protons.
   b. They have the same mass number.
   c. They have similar chemical properties.
   d. They have the same number of total electrons.

6. The organization of the periodic table is based on __________.
   a. the number of protons in an atom
   b. the mass number of an atom
   c. the number of neutrons in an atom
   d. the average atomic mass of an element

7. Elements with some properties of metals and some properties of nonmetals are known as __________.
   a. alkali metals **c.** halogens
   b. semiconductors **d.** noble gases

8. An atom of which of the following elements is unlikely to form a positively charged ion?
   a. potassium, K **c.** barium, Ba
   b. selenium, Se **d.** silver, Ag

9. Atoms of Group 18 elements are inert because __________.
   a. they combine to form molecules
   b. they have no valence electrons
   c. they have filled inner energy levels
   d. they have filled outermost energy levels

10. Which of the following statements about krypton is not true?
   a. Its molar mass is 83.80 g/mol Kr.
   b. Its atomic number is 36.
   c. One mole of krypton atoms has a mass of 41.90 g.
   d. It is a noble gas.

Using Vocabulary

11. How many *protons* and *neutrons* does a silicon, Si, atom have, and where are each of these subatomic particles located? How many *electrons* does a silicon atom have?

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SCILINKS NSTA

TOPIC: Silicon
GO TO: www.scilinks.org
KEYWORD: HK1037

CHAPTER 3 REVIEW

12. Explain why different atoms of the same element always have the same *atomic number* but can have different *mass numbers*. What are these different atoms called?
13. Distinguish between the following:
    - a. an *atom* and a *molecule*
    - b. an *atom* and an *ion*
    - c. a *cation* and an *anion*
14. How is the *periodic law* demonstrated with the *halogens*?
15. What does an element's *molar mass* tell you about the element?

BUILDING MATH SKILLS

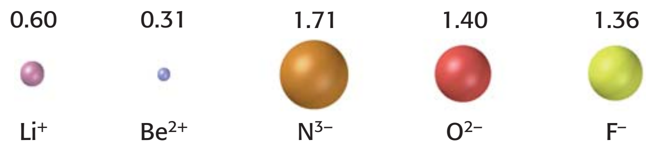
16. **Graphing** Use a graphing calculator, a computer spreadsheet, or a graphing program to plot the atomic number on the *x*-axis and the average atomic mass in amu on the *y*-axis for the transition metals in Period 4 of the periodic table (from scandium to zinc). Do you notice a break in the trend near cobalt? Explain why elements with larger atomic numbers do not necessarily have larger atomic masses.

    COMPUTER SKILL

17. **Converting Mass to Amount** For an experiment you have been asked to do, you need 1.5 g of iron. How many moles of iron do you need?
18. **Converting Mass to Amount** James is holding a balloon that contains 0.54 g of helium gas. What amount of helium is this?
19. **Converting Amount to Mass** A pure gold bar is made of 19.55 mol of gold. What is the mass of the bar in grams?
20. **Converting Amount to Mass** Robyn recycled 15.1 mol of aluminum last month. What mass of aluminum in grams did she recycle?

THINKING CRITICALLY

21. **Creative Thinking** Some forces push two atoms apart while other forces pull them together. Describe how the subatomic particles in each atom interact to produce these forces.
22. **Applying Knowledge** Explain why magnesium forms ions with the formula Mg^{2+}, not Mg^{+} or Mg^{-}.
23. **Evaluating Data** The figure below shows relative ionic radii for positive and negative ions of elements in Period 2 of the periodic table. Explain the trend in ion size as you move from left to right across the periodic table. Why do the negative ions have larger radii than the positive ions?



24. **Creative Thinking** Although carbon and lead are in the same group, some of their properties are very different. Propose a reason for this. (**Hint:** Look at the periodic table to locate each element and find out how each is classified.)
25. **Problem Solving** How does halving the amount of a sample of an element affect the sample's mass?

DEVELOPING LIFE/WORK SKILLS

26. **Locating Information** Some "neon" signs contain substances other than neon to produce different colors. Design your own lighted sign, and find out which substances you could use to produce the colors you want your sign to be.

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27. Making Decisions Suppose you have only 1.9 g of sulfur for an experiment and you must do three trials using 0.030 mol of S each time. Do you have enough sulfur?

28. Communicating Effectively The study of the nucleus produced a new field of medicine called nuclear medicine. Pretend you are writing an article for a hospital newsletter. Describe how radioactive substances called tracers are sometimes used to detect and treat diseases.

WRITING SKILL

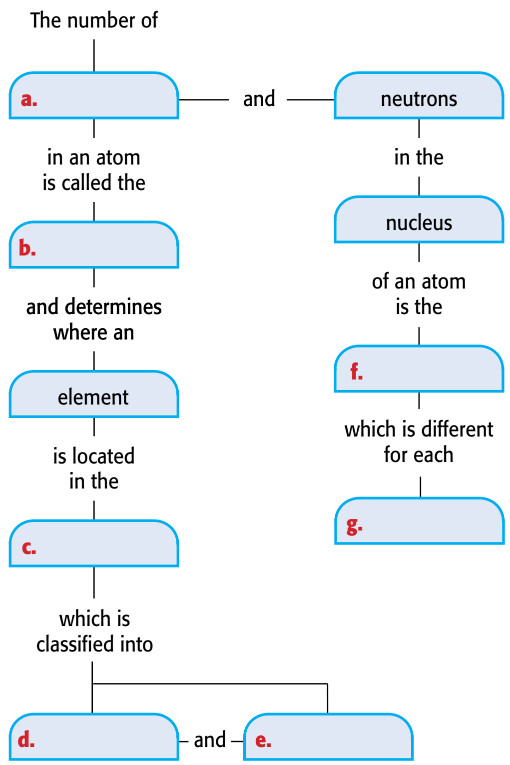
29. Working Cooperatively With a group of your classmates, make a list of 10 elements and their average atomic masses. Calculate the amount in moles for 6.0 g of each element. Rank your elements from the element with the greatest amount to the element with the least amount in a 6.0 g sample. Do you notice a trend in the amounts as atomic number increases? Explain why or why not.

INTEGRATING CONCEPTS

30. Connection to Health You can keep your bones healthy by eating 1200–1500 mg of calcium a day. Use the table below to make a list of the foods you might eat in a day to satisfy your body's need for calcium. How does your typical diet compare with this?

Item, serving size	Calcium (mg)
Plain lowfat yogurt, 1 cup	415
Ricotta cheese, 1/2 cup	337
Skim milk, 1 cup	302
Cheddar cheese, 1 ounce	213
Cooked spinach, 1/2 cup	106
Vanilla ice cream, 1/2 cup	88

31. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



32. Connection to Physics The big bang theory suggests that the universe began with an enormous explosion. What was formed as a result of the big bang? Describe the matter that was present after the explosion. How much time passed before the elements as we know them were formed?

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SCILINKS NSTA

TOPIC: Origin of elements
GO TO: www.scilinks.org
KEYWORD: HK1038

Design Your Own Lab

Comparing the Physical Properties of Elements

Introduction

How can you distinguish metal elements by analyzing their physical properties?

Objectives

- ***Determine*** which physical properties can help you ***distinguish*** between different metals.
- ***Identify*** unknown metals by ***comparing*** the data you collect with reference information.

Materials

several unknown metal samples
balance
graduated cylinder
water
several beakers
ice
magnet
stopwatch
metric ruler
wax
hot plate

Safety Needs

safety goggles
gloves
laboratory apron

Identifying Metal Elements

1. In this lab, you will identify samples of unknown metals by comparing the data you collect with reference information listed in the table at right. Use at least two of the physical properties listed in the table to identify each metal.

Deciding Which Physical Properties You Will Analyze

2. Density is the mass per unit volume of a substance. If the metal is box-shaped, you can measure its length, width, and height, and then use these measurements to calculate the metal's volume. If the shape of the metal is irregular, you can add the metal to a known volume of water and determine what volume of water is displaced.

3. Relative hardness indicates how easy it is to scratch a metal. A metal with a higher value can scratch a metal with a lower value, but not vice versa.

4. Relative heat conductivity indicates how quickly a metal heats or cools. A metal with a value of 100 will heat or cool twice as quickly as a metal with a value of 50.

5. If a magnet placed near a metal attracts the metal, then the metal has been magnetized by the magnet.

Designing Your Experiment

6. With your lab partner(s), decide how you will use the materials provided to identify each metal you are given. There is more than one way to measure some of the physical properties that are listed, so you might not use all of the materials that are provided.

7. In your lab report, list each step you will perform in your experiment.

8. Have your teacher approve your plan before you carry out your experiment.

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Physical Properties of Some Metals

Metal	Density (g/mL)	Relative hardness	Relative heat conductivity	Magnetized by magnet?
Aluminum (Al)	2.7	28	100	No
Iron (Fe)	7.9	50	34	Yes
Nickel (Ni)	8.9	67	38	Yes
Tin (Sn)	7.3	19	28	No
Tungsten (W)	19.3	100	73	No
Zinc (Zn)	7.1	28	49	No

Performing Your Experiment

9. After your teacher approves your plan, carry out your experiment. Keep in mind that the more careful your measurements are, the easier it will be for you to identify the unknown metals.
10. Record all the data you collect and any observations you make in your lab report.

Analyzing Your Results

1. Make a table listing the physical properties you compared and the data you collected for each of the unknown metals.
2. Which metals were you given? Explain the reasoning you used to identify each metal.
3. Which physical properties were the easiest for you to measure and compare? Which were the hardest? Explain why.
4. What would happen if you tried to scratch aluminum foil with zinc?
5. Explain why it would be difficult to distinguish between iron and nickel unless you calculate each metal's density.
6. Suppose you find a metal fastener and determine that its density is 7 g/mL. What are two ways you could determine whether the unknown metal is tin or zinc?

Defending Your Conclusions

7. Suppose someone gives you an alloy that is made of both zinc and nickel. In general, how do you think the physical properties of the alloy would compare with those of each individual metal?