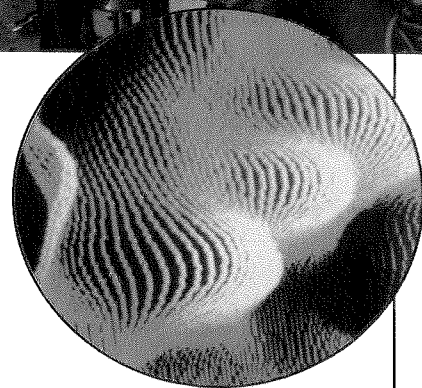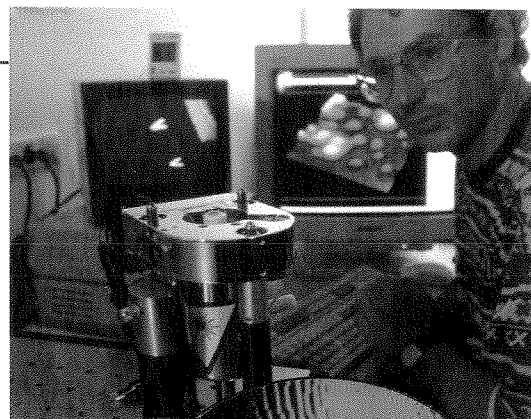# Electron Microscopy

Within 30 years of J.J. Thomson's discovery of the electron, scientists were studying how to produce images of objects by using an electron beam. In 1931, German scientists Ernst Ruska and Max Knoll built the first electron microscope. While an ordinary light microscope uses a beam of light and lenses to magnify objects, an electron microscope uses an electron beam and "lenses" consisting of magnetic or electric fields. A typical light microscope is capable of magnifying an object 1000 times. An electron microscope can magnify an object over 100,000 times. **Interpreting Photographs** *What characteristics of the images below provide the viewer with a sense of scale?*

Biochemistry A scientist uses an electron microscope to look at the surface of DNA molecules.

Microelectronics In the colorized electron micrograph below, a wood ant (*Formica fusca*), about 5 mm long, holds a microchip in its jaws. Microelectronics engineers use electron microscopes to measure and analyze the characteristics of microcircuits.
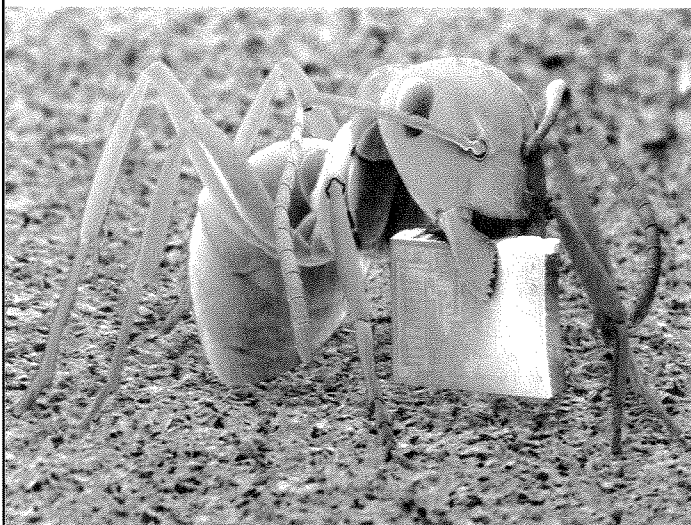
Biology A dust mite (*Dermatophagoides pteronyssinus*), smaller than the period at the end of this sentence, sits on the point of a sewing needle.

4.3 Distinguishing Among Atoms

Guide for Reading

Key Concepts
- What makes one element different from another?
- How do you find the number of neutrons in an atom?
- How do isotopes of an element differ?
- How do you calculate the atomic mass of an element?
- Why is a periodic table useful?

Vocabulary
atomic number
mass number
isotopes
atomic mass unit (amu)
atomic mass
periodic table
period
group

Reading Strategy
Building Vocabulary As you read the section, write a definition of each vocabulary term in your own words.

Connecting to Your World

Fruits and vegetables come in different varieties. For example, a grocery store might sell three varieties of apples: Granny Smith, Red Delicious, and Golden Delicious. Apple varieties can differ in color, size, texture, aroma, and taste. Just as apples come in different varieties, a chemical element can come in different "varieties" called isotopes. In this section, you will learn how one isotope of an element differs from another.
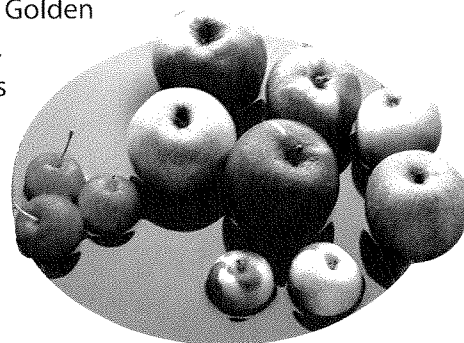
Atomic Number

Atoms are composed of protons, neutrons, and electrons. Protons and neutrons make up the nucleus. Electrons surround the nucleus. How, then, are atoms of hydrogen, for example, different from atoms of oxygen? Look at Table 4.2. Notice that a hydrogen atom has one proton, but an oxygen atom has eight protons. **Elements are different because they contain different numbers of protons.**

The **atomic number** of an element is the number of protons in the nucleus of an atom of that element. Because all hydrogen atoms have one proton, the atomic number of hydrogen is 1. Similarly, because all oxygen atoms have eight protons, the atomic number of oxygen is 8. The atomic number identifies an element. For each element listed in Table 4.2, the number of protons equals the number of electrons. Remember that atoms are electrically neutral. Thus, the number of electrons (negatively charged particles) must equal the number of protons (positively charged particles).

Table 4.2

| Atoms of the First Ten Elements						
Name	Symbol	Atomic number	Protons	Neutrons*	Mass number	Number of electrons
Hydrogen	H	1	1	0	1	1
Helium	He	2	2	2	4	2
Lithium	Li	3	3	4	7	3
Beryllium	Be	4	4	5	9	4
Boron	B	5	5	6	11	5
Carbon	C	6	6	6	12	6
Nitrogen	N	7	7	7	14	7
Oxygen	O	8	8	8	16	8
Fluorine	F	9	9	10	19	9
Neon	Ne	10	10	10	20	10

*Number of neutrons in the most abundant isotope. Isotopes are introduced later in Section 4.3.

Understanding Atomic Number

The element nitrogen (N), shown here in liquid form, has an atomic number of 7. How many protons and electrons are in a neutral nitrogen atom?
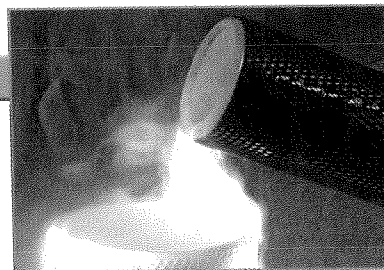
1 Analyze *Identify the relevant concepts.*

The atomic number gives the number of protons, which in a neutral atom equals the number of electrons.

2 Solve *Apply the concepts to this problem.*

The atomic number of nitrogen is 7, which means that a neutral nitrogen atom has 7 protons and 7 electrons.

Practice Problems

15. Complete the table.

Element	Atomic number	Protons	Electrons
K	19	(a)	19
(b)	(c)	(d)	5
S	16	(e)	(f)
V	(g)	23	(h)

16. How many protons and electrons are in each atom?
  a. fluorine (atomic number = 9)
  b. calcium (atomic number = 20)
  c. aluminum (atomic number = 13)

Interactive Textbook

Problem-Solving 4.15 Solve Problem 15 with the help of an interactive guided tutorial.

_____ with ChemASAP

Mass Number

You know that most of the mass of an atom is concentrated in its nucleus and depends on the number of protons and neutrons. The total number of protons and neutrons in an atom is called the **mass number.** Look again at Table 4.2 and note the mass numbers of helium and carbon. A helium atom has two protons and two neutrons, so its mass number is 4. A carbon atom, which has six protons and six neutrons, has a mass number of 12.

If you know the atomic number and mass number of an atom of any element, you can determine the atom's composition. Table 4.2 shows that an oxygen atom has an atomic number of 8 and a mass number of 16. Because the atomic number equals the number of protons, which equals the number of electrons, an oxygen atom has eight protons and eight electrons. The mass number of oxygen is equal to the number of protons plus the number of neutrons. The oxygen atom, then, has eight neutrons, which is the difference between the mass number and the atomic number $(16 - 8 = 8)$. 👉 **The number of neutrons in an atom is the difference between the mass number and atomic number.**

Number of neutrons = mass number − atomic number

The composition of any atom can be represented in shorthand notation using atomic number and mass number. Figure 4.8 shows how an atom of gold is represented using this notation. The chemical symbol Au appears with two numbers written to its left. The atomic number is the subscript. The mass number is the superscript.

You can also refer to atoms by using the mass number and the name of the element. For example, $^{197}_{79}$Au may be written as gold-197.

Checkpoint *How do you calculate mass number?*

Figure 4.8 Au is the chemical symbol for gold. **Applying Concepts** *How many electrons does a gold atom have?*

$^{197}_{79}$ **Au**

Determining the Composition of an Atom

How many protons, electrons, and neutrons are in each atom?

	Atomic number	Mass number
a. Beryllium (Be)	4	9
b. Neon (Ne)	10	20
c. Sodium (Na)	11	23

① Analyze *List the knowns and the unknowns.*

Knowns	Unknowns
• atomic number	• number of protons = ?
• mass number	• number of electrons = ?
	• number of neutrons = ?

Use the definitions of atomic number and mass number to calculate the numbers of protons, electrons, and neutrons.

② Calculate *Solve for the unknowns.*

number of electrons = atomic number
a. 4   **b.** 10   **c.** 11
number of protons = atomic number
a. 4   **b.** 10   **c.** 11
number of neutrons = mass number-atomic number
a. $9 - 4 = 5$ **b.** $20 - 10 = 10$ **c.** $23 - 11 = 12$

③ Evaluate *Do the results make sense?*

For each atom, the mass number equals the number of protons plus the number of neutrons. The results make sense.

17. How many neutrons are in each atom?

 a. $^{16}_{8}O$ **b.** $^{32}_{16}S$ **c.** $^{108}_{47}Ag$

 d. $^{80}_{35}Br$ **e.** $^{207}_{82}Pb$

18. Use Table 4.2 to express the composition of each atom in shorthand form.
 a. carbon-12   **b.** fluorine-19   **c.** beryllium-9

Interactive Textbook

Problem-Solving 4.17
Solve Problem 17 with the help of an interactive guided tutorial.

with ChemASAP

Isotopes

Figure 4.9 shows that there are three different kinds of neon atoms. How do these atoms differ? All have the same number of protons (10) and electrons (10), but they each have different numbers of neutrons. **Isotopes** are atoms that have the same number of protons but different numbers of neutrons. **Because isotopes of an element have different numbers of neutrons, they also have different mass numbers.** Despite these differences, isotopes are chemically alike because they have identical numbers of protons and electrons, which are the subatomic particles responsible for chemical behavior.
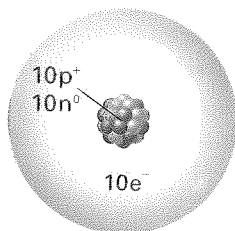
Neon-20
10 protons
10 neutrons
10 electrons
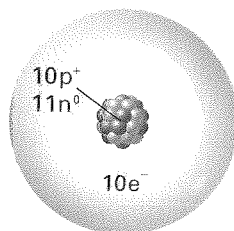
Neon-21
10 protons
11 neutrons
10 electrons

Neon-22
10 protons
12 neutrons
10 electrons

There are three known isotopes of hydrogen. Each isotope of hydrogen has one proton in its nucleus. The most common hydrogen isotope has no neutrons. It has a mass number of 1 and is called hydrogen-1 ($^1_1$H) or simply hydrogen. The second isotope has one neutron and a mass number of 2. It is called either hydrogen-2 ($^2_1$H) or deuterium. The third isotope has two neutrons and a mass number of 3. This isotope is called hydrogen-3 ($^3_1$H) or tritium.

Figure 4.9 Neon-20, neon-21, and neon-22 are three isotopes of neon, a gaseous element used in lighted signs. *Comparing and Contrasting How are these isotopes different? How are they similar?*

✓Checkpoint) **What are three known isotopes of hydrogen?**

CONCEPTUAL PROBLEM 4.2

Writing Chemical Symbols of Isotopes

Diamonds are a naturally occurring form of elemental carbon. Two stable isotopes of carbon are carbon-12 and carbon-13. Write the symbol for each isotope using superscripts and subscripts to represent the mass number and the atomic number.
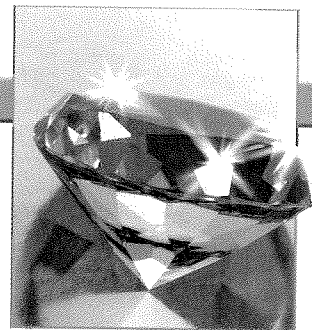
1 Analyze *Identify the relevant concepts.*

Isotopes are atoms that have the same number of protons but different numbers of neutrons. The composition of an atom can be expressed by writing the chemical symbol, with the atomic number as a subscript and the mass number as a superscript.

2 Solve *Apply the concepts to this problem.*

Based on Table 4.2, the symbol for carbon is C and the atomic number is 6. The mass number for each isotope is given by its name. For carbon-12, the symbol is $^{12}_6$C. For carbon-13, the symbol is $^{13}_6$C.

Practice Problems

19. Three isotopes of oxygen are oxygen-16, oxygen-17, and oxygen-18. Write the symbol for each, including the atomic number and mass number.

20. Three isotopes of chromium are chromium-50, chromium-52, and chromium-53. How many neutrons are in each isotope, given that chromium has an atomic number of 24?

*i*nteractive
Textbook

Problem-Solving 4.20
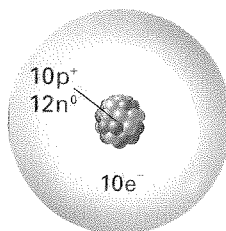Solve Problem 20 with the help of an interactive guided tutorial.

with ChemASAP

Atomic Mass

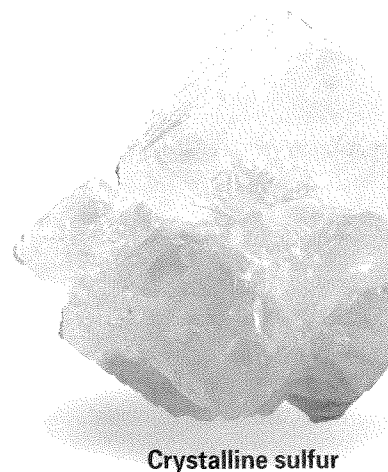A glance back at Table 4.1 on page 106 shows that the actual mass of a proton or a neutron is very small (1.67×10^{-24} g). The mass of an electron is 9.11×10^{-28} g, which is negligible in comparison. Given these values, the mass of even the largest atom is incredibly small. Since the 1920s, it has been possible to determine these tiny masses by using a mass spectrometer. With this instrument, the mass of a fluorine atom was found to be 3.155×10^{-23} g, and the mass of an arsenic atom was found to be 1.244×10^{-22} g. Such data about the actual masses of individual atoms can provide useful information, but, in general, these values are inconveniently small and impractical to work with. Instead, it is more useful to compare the relative masses of atoms using a reference isotope as a standard. The isotope chosen is carbon-12. This isotope of carbon was assigned a mass of exactly 12 atomic mass units. An **atomic mass unit (amu)** is defined as one twelfth of the mass of a carbon-12 atom. Using these units, a helium-4 atom, with a mass of 4.0026 amu, has about one-third the mass of a carbon-12 atom. On the other hand, a nickel-60 atom has about five times the mass of a carbon-12 atom.

A carbon-12 atom has six protons and six neutrons in its nucleus, and its mass is set as 12 amu. The six protons and six neutrons account for nearly all of this mass. Therefore the mass of a single proton or a single

Table 4.3

Natural Percent Abundance of Stable Isotopes of Some Elements

Name	Symbol	Natural percent abundance	Mass (amu)	Average atomic mass
Hydrogen	$^{1}_{1}H$	99.985	1.0078	
	$^{2}_{1}H$	0.015	2.0141	1.0079
	$^{3}_{1}H$	negligible	3.0160	
Helium	$^{3}_{2}He$	0.0001	3.0160	4.0026
	$^{4}_{2}He$	99.9999	4.0026	
Carbon	$^{12}_{6}C$	98.89	12.000	12.011
	$^{13}_{6}C$	1.11	13.003	
Nitrogen	$^{14}_{7}N$	99.63	14.003	14.007
	$^{15}_{7}N$	0.37	15.000	
Oxygen	$^{16}_{8}O$	99.759	15.995	
	$^{17}_{8}O$	0.037	16.995	15.999
	$^{18}_{8}O$	0.204	17.999	
Sulfur	$^{32}_{16}S$	95.002	31.972	
	$^{33}_{16}S$	0.76	32.971	32.06
	$^{34}_{16}S$	4.22	33.967	
	$^{36}_{16}S$	0.014	35.967	
Chlorine	$^{35}_{17}Cl$	75.77	34.969	35.453
	$^{37}_{17}Cl$	24.23	36.966	

Crystalline sulfur

$^{35}_{17}\text{Cl}$ $^{35}_{17}\text{Cl}$ $^{35}_{17}\text{Cl}$ $^{37}_{17}\text{Cl}$

$17\,p^+$
$18\,n^0$

$17\,p^+$
$18\,n^0$

$17\,p^+$
$18\,n^0$

$17\,p^+$
$20\,n^0$

Total number of protons in three $^{35}_{17}\text{Cl}$ atoms and one $^{37}_{17}\text{Cl}$ atom
$(17 + 17 + 17 + 17)$

Total number of neutrons in three $^{35}_{17}\text{Cl}$ atoms and one $^{37}_{17}\text{Cl}$ atom
$(18 + 18 + 18 + 20)$

$$\frac{68 + 74}{4} = 35.5 \text{ amu}$$

Weighted Average Mass of a Chlorine Atom
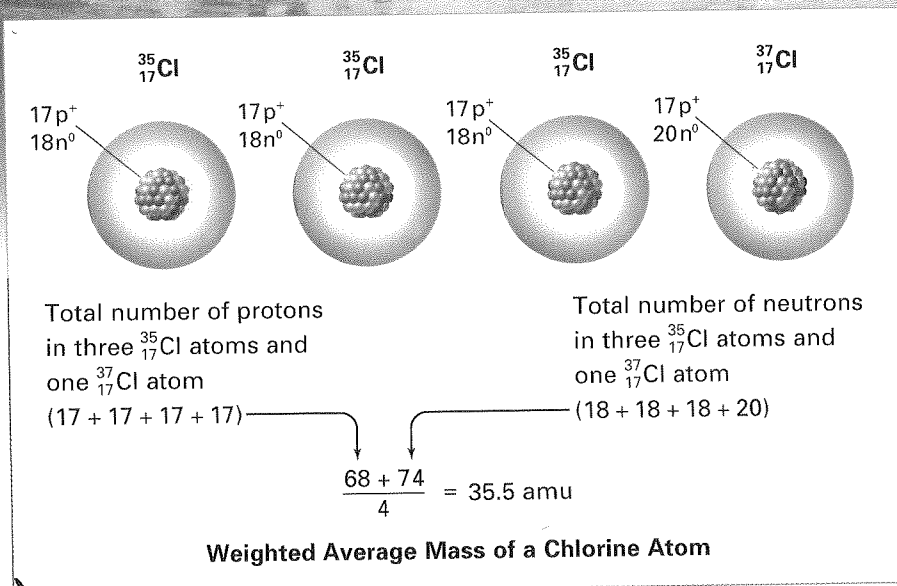
Figure 4.10 Chlorine is a reactive element used to disinfect swimming pools. Chlorine occurs as two isotopes: chlorine-35 and chlorine-37. Because there is more chlorine-35 than chlorine-37, the atomic mass of chlorine, 35.453 amu, is closer to 35 than to 37. **Evaluating** *How does a weighted average differ from an arithmetic mean?*

neutron is about one-twelfth of 12 amu, or about 1 amu. Because the mass of any single atom depends mainly on the number of protons and neutrons in the nucleus of the atom, you might predict that the atomic mass of an element should be a whole number. However, that is not usually the case.

In nature, most elements occur as a mixture of two or more isotopes. Each isotope of an element has a fixed mass and a natural percent abundance. Consider the three isotopes of hydrogen discussed earlier in this section. According to Table 4.3, almost all naturally occurring hydrogen (99.985%) is hydrogen-1. The other two isotopes are present in trace amounts. Notice that the atomic mass of hydrogen listed in Table 4.3 (1.0079 amu) is very close to the mass of hydrogen-1 (1.0078 amu). The slight difference takes into account the larger masses, but smaller amounts, of the other two isotopes of hydrogen.

Now consider the two stable isotopes of chlorine listed in Table 4.3: chlorine-35 and chlorine-37. If you calculate the arithmetic mean of these two masses ((34.969 amu + 36.966 amu)/2), you get an average atomic mass of 35.968 amu. However, this value is higher than the actual value of 35.453. To explain this difference, you need to know the natural percent abundance of the isotopes of chlorine. Chlorine-35 accounts for 75% of the naturally occurring chlorine atoms; chlorine-37 accounts for only 25%. See Figure 4.10. The **atomic mass** of an element is a weighted average mass of the atoms in a naturally occurring sample of the element. A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

✓ Checkpoint *What is the atomic mass of an element?*

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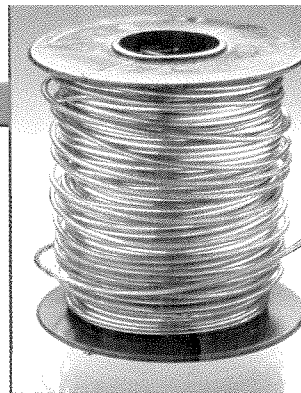**For:** Links on Isotopes
Visit: www.SciLinks.org
Web Code: cdn-1043

Using Atomic Mass to Determine the Relative Abundance of Isotopes

The atomic mass of copper is 63.546 amu. Which of copper's two isotopes is more abundant: copper-63 or copper-65?

① **Analyze** *Identify the relevant concepts.*

The atomic mass of an element is the weighted average mass of the atoms in a naturally occurring sample of the element. A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

② **Solve** *Apply the concepts to this problem.*

The atomic mass of 63.546 amu is closer to 63 than to 65. Because the atomic mass is a weighted average of the isotopes, copper-63 must be more abundant than copper-65.

Practice Problems

21. Boron has two isotopes: boron-10 and boron-11. Which is more abundant, given that the atomic mass of boron is 10.81 amu?

22. There are three isotopes of silicon; they have mass numbers of 28, 29, and 30. The atomic mass of silicon is 28.086 amu. Comment on the relative abundance of these three isotopes.

Interactive Textbook

Problem-Solving 4.21 Solve Problem 21 with the help of an interactive guided tutorial.

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Now that you know that the atomic mass of an element is a weighted average of the masses of its isotopes, you can determine atomic mass based on relative abundance. To do this, you must know three values: the number of stable isotopes of the element, the mass of each isotope, and the natural percent abundance of each isotope. **To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.** The resulting sum is the weighted average mass of the atoms of the element as they occur in nature.

You can calculate the atomic masses listed in Table 4.3 based on the given masses and natural abundances of the isotopes for each element. For example, carbon has two stable isotopes: carbon-12, which has a natural abundance of 98.89%, and carbon-13, which has natural abundance of 1.11%. The mass of carbon-12 is 12.000 amu; the mass of carbon-13 is 13.003 amu. The atomic mass is calculated as follows.

$$\text{Atomic mass of carbon} = (12.000 \text{ amu} \times 0.9889) + (13.003 \text{ amu} \times 0.0111)$$
$$= 12.011 \text{ amu}$$

✓Checkpoint *What three values must be known in order to calculate the atomic mass of an element?*

Calculating Atomic Mass

Element X has two natural isotopes. The isotope with a mass of 10.012 amu (^{10}X) has a relative abundance of 19.91%. The isotope with a mass of 11.009 amu (^{11}X) has a relative abundance of 80.09%. Calculate the atomic mass of this element.

1 Analyze *List the knowns and the unknown.*

Knowns
- isotope ^{10}X:
  mass = 10.012 amu
  relative abundance = 19.91% = 0.1991
- isotope ^{11}X:
  mass = 11.009 amu
  relative abundance = 80.09% = 0.8009

Unknown
- atomic mass of element X = ?

The mass each isotope contributes to the element's atomic mass can be calculated by multiplying the isotope's mass by its relative abundance. The atomic mass of the element is the sum of these products.

2 Calculate *Solve for the unknown.*

for ^{10}X: 10.012 amu $\times$ 0.1991 =   1.993 amu
for ^{11}X: 11.009 amu $\times$ 0.8009 =   8.817 amu
for element X: atomic mass = 10.810 amu

3 Evaluate *Does the result make sense?*

The calculated value is closer to the mass of the more abundant isotope, as would be expected.

Practice Problems

23. The element copper has naturally occurring isotopes with mass numbers of 63 and 65. The relative abundance and atomic masses are 69.2% for mass = 62.93 amu, and 30.8% for mass = 64.93 amu. Calculate the average atomic mass of copper.

24. Calculate the atomic mass of bromine. The two isotopes of bromine have atomic masses and relative abundance of 78.92 amu (50.69%) and 80.92 amu (49.31%).

Bromine

1A																	8A
1 **H**	2A											3A	4A	5A	6A	7A	2 **He**
3 **Li**	4 **Be**											5 **B**	6 **C**	7 **N**	8 **O**	9 **F**	10 **Ne**
11 **Na**	12 **Mg**	3B	4B	5B	6B	7B	⎡——8B——⎤			1B	2B	13 **Al**	14 **Si**	15 **P**	16 **S**	17 **Cl**	18 **Ar**
19 **K**	20 **Ca**	21 **Sc**	22 **Ti**	23 **V**	24 **Cr**	25 **Mn**	26 **Fe**	27 **Co**	28 **Ni**	29 **Cu**	30 **Zn**	31 **Ga**	32 **Ge**	33 **As**	34 **Se**	35 **Br**	36 **Kr**
37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 **Xe**
55 **Cs**	56 **Ba**	71 **Lu**	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl**	82 **Pb**	83 **Bi**	84 **Po**	85 **At**	86 **Rn**
87 **Fr**	88 **Ra**	103 **Lr**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Ds**	111 **Rg**	112 **Uub**		114 **Uuq**				

57 **La**	58 **Ce**	59 **Pr**	60 **Nd**	61 **Pm**	62 **Sm**	63 **Eu**	64 **Gd**	65 **Tb**	66 **Dy**	67 **Ho**	68 **Er**	69 **Tm**	70 **Yb**
89 **Ac**	90 **Th**	91 **Pa**	92 **U**	93 **Np**	94 **Pu**	95 **Am**	96 **Cm**	97 **Bk**	98 **Cf**	99 **Es**	100 **Fm**	101 **Md**	102 **No**

Figure 4.11 Elements are arranged in the modern periodic table in order of atomic number. **Interpreting Diagrams** *How many elements are in Period 2? In Group 2A?*

The Periodic Table—A Preview

Now that you can differentiate between atoms of different elements and also between isotopes of the same element, you need to understand how the elements are organized with respect to each other. A **periodic table** is an arrangement of elements in which the elements are separated into groups based on a set of repeating properties. ⊙ A periodic table allows you to easily compare the properties of one element (or a group of elements) to another element (or group of elements).

Figure 4.11 shows the most commonly used form of the modern periodic table, sometimes called the long form. Each element is identified by its symbol placed in a square. The atomic number of the element is shown centered above the symbol. Notice that the elements are listed in order of increasing atomic number, from left to right and top to bottom. Hydrogen (H), the lightest element, is in the top left corner. Helium (He), atomic number 2, is at the top right. Lithium (Li), atomic number 3, is at the left end of the second row.

Each horizontal row of the periodic table is called a **period.** There are seven periods in the modern periodic table. The number of elements per period ranges from 2 (hydrogen and helium) in Period 1, to 32 in Period 6. Within a given period, the properties of the elements vary as you move across it from element to element. This pattern of properties then repeats as you move to the next period.

Each vertical column of the periodic table is called a **group,** or family. Elements within a group have similar chemical and physical properties. Note that each group is identified by a number and the letter A or B. For example, Group 2A contains the elements beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra). You will learn more about specific trends in the periodic table in Chapter 6.

Archaeologist

Archaeologists are detectives of the past, sifting for clues that uncover secrets of past civilizations. Archaeologists excavate ancient cities and dwellings looking for artifacts that indicate what kinds of foods ancient people ate, what types of tools they used, and how they interacted with one another as a society. Often, archaeologists must draw conclusions based on indirect evidence.

Knowing when an event occurred or when an artifact was made can provide important information. Archaeologists use techniques such as radiometric-dating, in which a sample is dated by measuring the concentration of certain isotopes, such as carbon-14. This method tells them the age of a sample within a certain range, and is used with the greatest accuracy for samples no more than 10,000 years old.

Archaeologists also perform chemical tests on artifacts to determine their composition. For example, archaeologists might analyze the glazes used on pottery, or the dyes used in clothing. Archaeologists may also use chemicals to preserve artifacts that have been unearthed, so that the artifacts can be examined without being damaged.

Archaeology requires a background in both history and science. Archaeologists often spend as much time in the laboratory studying their finds as they do out in the field excavating sites. Archaeologists take courses in archaeological techniques, biology, anatomy, chemistry, math, and history.

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4.3 Section Assessment

25. **Key Concept** What distinguishes the atoms of one element from the atoms of another?

26. **Key Concept** What equation tells you how to calculate the number of neutrons in an atom?

27. **Key Concept** How do the isotopes of a given element differ from one another?

28. **Key Concept** How is atomic mass calculated?

29. **Key Concept** What makes the periodic table such a useful tool?

30. What does the number represent in the isotope platinum-194? Write the symbol for this atom using superscripts and subscripts.

31. The atomic masses of elements are generally not whole numbers. Explain why.

32. List the number of protons, neutrons, and electrons in each pair of isotopes.

   a. $^6_3Li, ^7_3Li$ b. $^{42}_{20}Ca, ^{44}_{20}Ca$ c. $^{78}_{34}Se, ^{80}_{34}Se$

33. Name two elements that have properties similar to those of the element calcium (Ca).

Elements ▶ Handbook

Elements Within You Read page R5 of the Elements Handbook. Identify the five most abundant elements in the human body, and locate them on the periodic table.

Interactive Textbook

Assessment 4.3 Test yourself on the concepts in Section 4.3.

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